8 ix
m

NASA CR-112326

EARTH ORBITAL EXPERIMENT PROGRAM
AND
REQUIREMENTS STUDY

VOLUME 2

MANNED SPACEFLIGHT CAPABILITY

(APPENDICES A, B, C)

(NASA-CR-112326) EARTH ORBITAL EXPERIMENT PROGRAM AND REQUIREMENTS STUDY. VOLUME 2: MANNED SPACEFLIGHT CAPABILITY (APPENDICES A, B, C) (McDonnell-Douglas Corp.) 593 p HC $31.75 CSCL 22A G3/30
N73-22779
Unclas
69827

Prepared under Contract No. NAS1-9464 by

McDONNELL DOUGLAS CORPORATION
5301 Bolsa Avenue
Huntington Beach, California 92647

for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

TABLE OF CONTENTS

(

FOREWORD

The information presented in this report summarizes three major steps toward production of a reference manual for planners of manned earth-orbital research activity. The reference manual will serve as one of the principal tools of a systems approach to experiment and mission planning based on an integrated consideration of candidate research programs and their attendant vehicle, mission, and technology development requirements.

The first major step toward preparation of the manual was the development of long-range goals and objectives suitable for NASA's activities during the 1970-1980 time period. This work was completed by NASA Headquarters with active center support and was published in September 1969 as a portion of a report for the President's Space Task Group entitled, "America's Next Decade in Space."

The second major step was a contractual study effort undertaken in September 1969 by McDonnell Douglas Astronautics Company-West with the TRW Systems Group, the IBM Federal Systems Division, and the RPC Corporation. The purpose of the study was to structure the NASA-developed goals and objectives into an orderly, system-oriented set of implementation requirements. The contractor examined, in depth, the orbital experiment program required to achieve the scientific, technological, and application objectives, and determined in a general way the capabilities required in future manned orbital programs to accommodate the defined experiments. Thus, the basic task of the contractor was to aid NASA in studying the useful and proper roles of manned and automated spacecraft by examining the implementation alternatives for NASA experiments.

The third major step presented in this document is the result of an integrated consideration of NASA's long-range goals and objectives, the system and mission requirements, and the alternative implementation plans. It will serve as a source of detailed information and methodology for use by NASA planners in development and justification of future programs.

Management

Technical direction (fig. 1) of the contracted study effort is the responsibility of the Advanced Aerospace Studies Branch (AASB) of the Space Systems Division (SSD) at the Langley Research Center (LRC). Technical guidance is provided by the Earth Orbital Experiment Program Steering Group which reports through the Planning Steering Group (PSG) to the Associate Administrator. Technical coordination is also maintained with appropriate personnel at ARC, GSFC, MSC, and MSFC.

The membership of the Steering Group (fig. 2) comprises representatives of th working groups of the PSG under the chairmanship of Dr. R. G. Wilson, Directo Advanced Programs, OSSA. The NASA Study Management Team is headed by Mr. W. R. Hook of the AASB. Technical support is supplied by elements of the Langley Research Center as required.

The contractor's Study Team is headed by Dr. H. L. Wolbers, MDAC, and the Senior Management Review Council is chaired by Mr. C. J. Dorrenbacher, Vice President, Advanced Systems and Technology, MDAC.

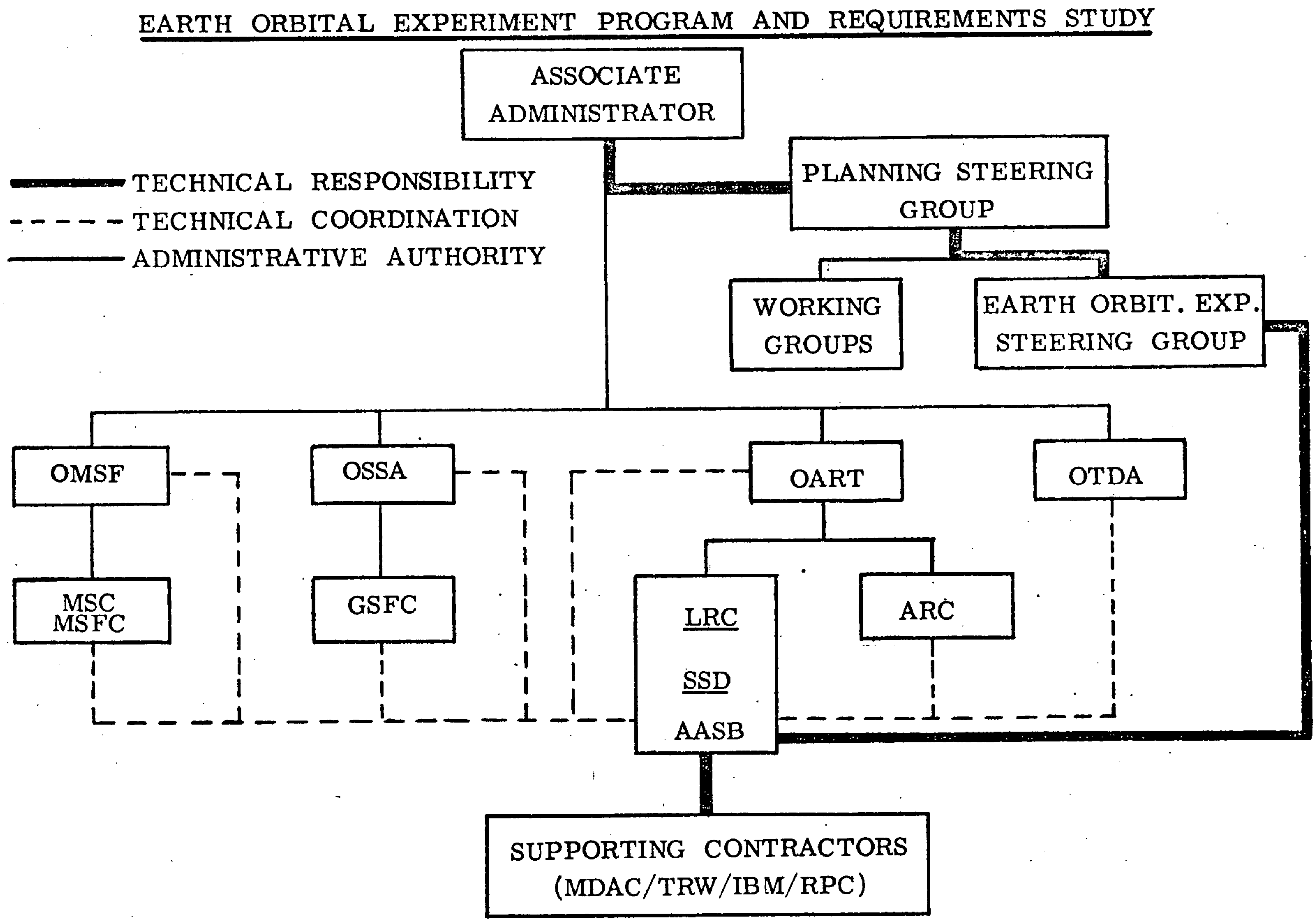


Figure 1. - Management Plan.

EARTH ORBITAL EXPERIMENT PROGRAM AND REQUIREMENTS STUDY

STEERING GROUP

CHAIRMAN:
R. WILSON, OSSA

VICE CHAIRMAN:
R. GUTHEIM, OSSA

R. DUNNING,	OART
B. MAGGIN,	OART
D. NOVIK,	OART
E. BRAZILL,	OMSF
R. JOHNSON,	OMSF
M. AUCREMANNE,	OSSA
E. EHRLICH,	OSSA
L. FONG,	OSSA
L. GOFF,	OSSA
A. SURES,	OSSA
W. HAYES,	LRC

ADVANCED AEROSPACE STUDIES BRANCH (LRC)

STUDY MGR., W. R. HOOK

DEP. C. P. LLEWELLYN
ASST. W. G. AYERS
ASST. K. A. EDWARDS
ASST. W. E. SIVERTSON
ASST. T. O. WILSON

F. O. ALLAMBY
E. C. HASTINGS
D. V. MADDALON
C. I. TYNAN

LRC SUPPORT

SPACE SYSTEMS DIV.
SPACE TECHNOLOGY DIV.
ENVIRONMENTAL AND SPACE SCIENCES DIV.
FLIGHT DYNAMICS AND CONTROL DIV.
INSTRUMENT RESEARCH DIV.
FLIGHT INSTRUMENTATION DIV.

SUPPORTING CONTRACTOR MANAGEMENT

MGR. H. L. WOLBERS, MDAC

DEP. J.W. WECHSLER, MDAC

ASST. A. ADELMAN, IBM

ASST. D. M. WALTZ, TRW

SENIOR MANAGEMENT REVIEW COUNCIL

CHAIRMAN:
C.J. DORRENBACHER, MDAC

P.A. CASTRUCCIO,	IBM
A.K. THIEL,	TRW
L. LARMORE,	MDAC
A.J. VANDERWEYDEN,	MDAC

Figure 2. - Study Team.

APPENDIX A

ORGANIZED OVERVIEW
CHARTS

MANNED SPACEFLIGHT CAPABILITY

INTRODUCTION
APPENDIX A

The organized overview method of analysis is described in Section 2, in general terms as well as specific detail for each of the six study disciplines. The organized overview charts derived in each of these disciplines are presented in this Appendix, as follows:

Manned Spaceflight Capability	Charts 1-1 through 1-90
Space Biology	Charts 2-1 through 2-14
Space Astronomy	Charts 3-1 through 3-42
Space Physics	Charts 4-1 through 4-17
Communications and Navigation	Charts 5-1 through 5-9
Earth Observations	Charts 6-1 through 6-29

Critical issues referred to at the lower levels of these charts are found in Tables 1 through 6 in Appendix B.

Chart 1-1. Organized Overview for Manned Spaceflight Capability

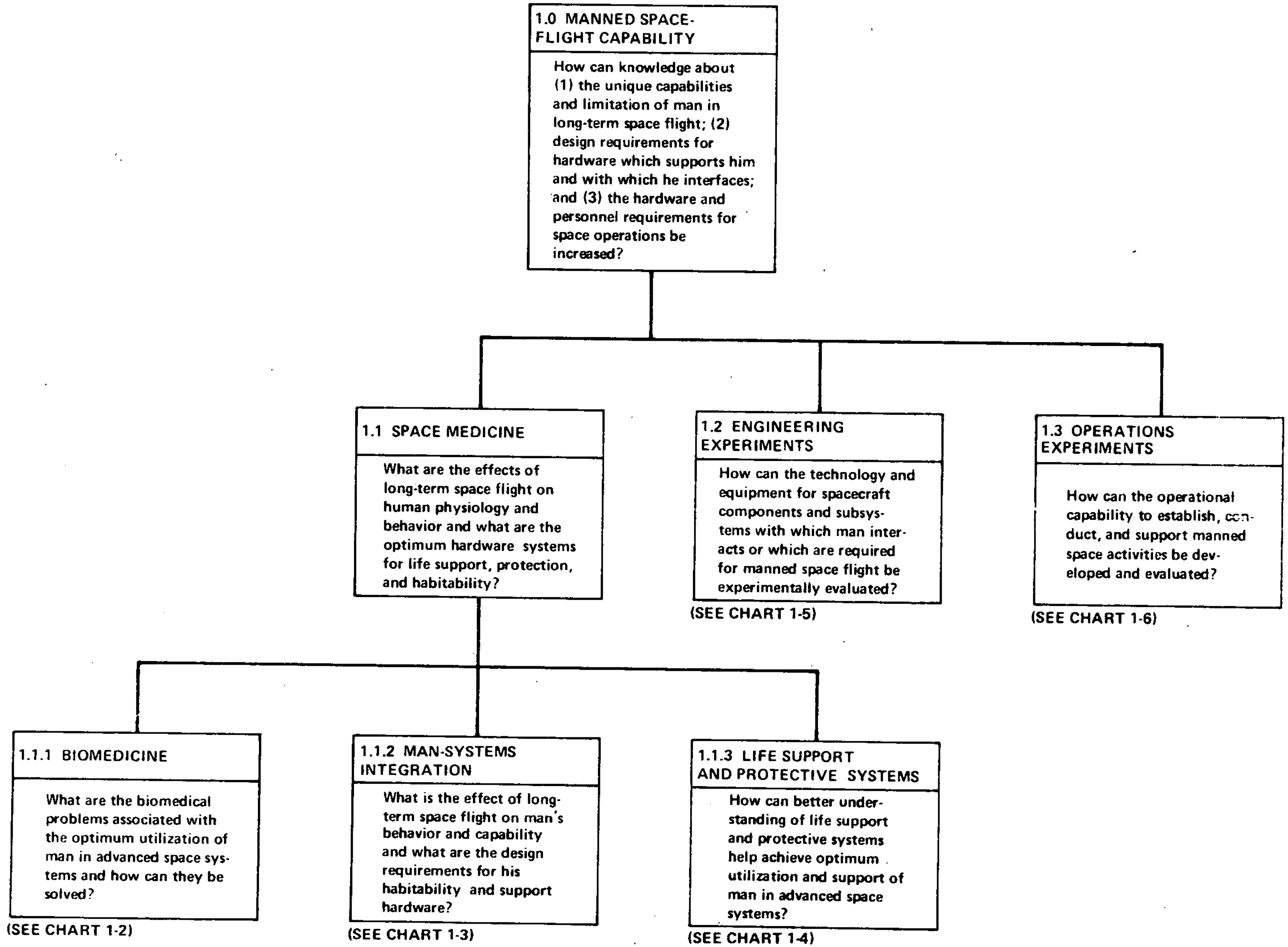


Chart 1-2. Manned Spaceflight Capability – Biomedicine

(SEE CHART 1-1)

1.1.1 BIOMEDICINE

What are the biomedical problems associated with the optimum utilization of man in advanced space systems and how can they be solved?

1.1.1.1 PHYSIOLOGICAL CHANGES

What changes occur in the physiological systems of man when he is exposed for prolonged durations to the spacecraft environment and what are the mechanisms associated with such changes?

1.1.1.2 MEDICAL PROBLEMS

What are the effects of the spacecraft environment on medical problems and their management?

(SEE CHART 1-15)

1.1.1.3 STRESS TOLERANCE CHANGES

What changes occur in tolerance limits to potential environmental stresses due to prolonged exposure to the spacecraft environment and how will these changes affect environmental control criteria?

(SEE CHART 1-16)

1.1.1.1.1 CARDIOVASCULAR

What changes occur in cardiovascular function and what are the mechanisms associated with the changes?

(SEE CHART 1-7)

1.1.1.1.2 RESPIRATORY

What changes occur in respiratory function and what are the mechanisms associated with the changes?

(SEE CHART 1-8)

1.1.1.1.3 NEUROLOGICAL

What changes occur in neurological function and what are the mechanisms associated with the changes?

(SEE CHART 1-9)

1.1.1.1.4 GASTROINTESTINAL

What changes occur in gastrointestinal function and what are the mechanisms associated with the changes?

(SEE CHART 1-10)

1.1.1.1.5 EXCRETORY FUNCTION AND FLUID BALANCE

What changes occur in excretory function and fluid balance and what are the mechanisms associated with the changes?

(SEE CHART 1-11)

1.1.1.1.6 METABOLISM AND MUSCULOSKELETAL FUNCTION

What changes occur in metabolism, including musculoskeletal function, and what are the mechanisms associated with the changes?

(SEE CHART 1-12)

1.1.1.1.7 HEMATOLOGY AND IMMUNOLOGY

What changes occur in hematology and immunology and what are the mechanisms associated with the changes?

(SEE CHART 1-13)

1.1.1.1.8 ENDOCRINE FUNCTION

What changes occur in endocrine function and what are the mechanisms associated with the changes?

(SEE CHART 1-14)

1.1.1.1.9 REPRODUCTIVE FUNCTIONS

What changes occur in reproductive function and what are the mechanisms associated with the changes?

(CRITICAL ISSUES IN TABLE 1)

Chart 1-3. Manned Spaceflight Capability – Man-System Integration

(SEE CHART 1-1)

1.1.2 MAN-SYSTEMS INTEGRATION

What is the effect of longterm spaceflight on man's vehavior and capability and what are the design requirements for his habitability and support hardware?

1.1.2.1 BEHAVIORAL RESEARCH

How can our understanding of man's behavior as an individual and as a group member, his capability to perform useful work, and his selection and training requirements for extended spaceflight be increased?

1.1.2.1.1 INDIVIDUAL BEHAVIOR

What is the influence of long-duration spaceflight on human behavior?

(SEE CHART 1-18)

1.1.2.1.2 HUMAN CAPABILITIES

How can human capabilities for performing physical and mental work as an operator and maintainer of space systems and as a scientific investigator be quantified and what is the appropriate man-machine mix?

(CRITICAL ISSUES IN TABLE 1)

1.1.2.1.3 GROUP STRUCTURE AND DYNAMICS

What is the influence of long-duration spaceflight on group dynamics and structure?

(CRITICAL ISSUES IN TABLE 1)

1.1.2.1.4 PERSONAL AND SOCIAL ADJUSTMENT

How can man's understanding of the individual and personality traits which are predictive of successful adjustment in spaceflight be increased?

(CRITICAL ISSUES IN TABLE 1)

1.1.2.1.5 SELECTION AND TRAINING

How can man's performance in space be enhanced through crew selection, techniques for maintenance of skills, and efficient training requirements analysis and implementation?

(CRITICAL ISSUES IN TABLE 1)

1.1.2.1.6 PERFORMANCE MONITORING AND ASSESSMENT

How can methods for performance monitoring and proficiency assessment during long-duration space missions be developed?

(CRITICAL ISSUES IN TABLE 1)

1.1.2.2 MAN-MACHINE RESEARCH

What are the design criteria for equipment which man interfaces or which is required to support him in long-duration spaceflight?

1.1.2.2.1 CONTROLS AND DISPLAYS

What are the design criteria and new technology needed for controls and displays with which crews of long-duration space missions must interact in performing systems management, information processing, and vehicle navigation and control?

(CRITICAL ISSUES IN TABLE 1)

1.1.2.2.2 LOCOMOTION AND RESTRAINT

How can techniques and equipment for astronaut restraint and locomotion both inside and outside the spacecraft be developed and evaluated?

(CRITICAL ISSUES IN TABLE 1)

1.1.2.2.3 HABITABILITY

How can methods, technology, and equipment for habitable living and working areas in long-duration space missions be developed and evaluated?

(SEE CHART 1-20)

1.1.2.2.4 WORK/REST/SLEEP CYCLES

How can man's understanding of circadian rhythms and diurnal cycles in space be increased and how can optimum work/rest/sleep cycles for long-duration space missions be developed and evaluated?

(SEE CHART 1-20)

1.1.2.2.5 PERFORMANCE AIDS

How can we identify, develop and evaluate aids for enhancement of human performance in long-duration space missions?

(SEE CHART 1-21)

1.1.2.2.6 SCHEDULING TECHNIQUES

How can man's understanding of techniques for constructing, modifying, and updating activity schedules for long-duration space missions be increased?

(CRITICAL ISSUES IN TABLE 1)

Chart 1-4. Manned Spaceflight Capability – Life Support and Protective Systems

(SEE CHART 1-1)

1.1.3 LIFE SUPPORT AND PROTECTIVE SYSTEMS

How can better understanding of Life Support and Protective Systems help achieve optimum utilization and support of man in advanced space systems?

1.1.3.1 DEVELOPMENT OF ATMOSPHERIC SUPPLY AND PRESSURE SYSTEM TECHNOLOGY

How can the development and understanding of atmospheric supply and pressurization system contribute to life support and protective systems, and what are the pertinent functions performed by the atmospheric supply and pressurization system?

(SEE CHART 1-22)

1.1.3.2 ATOMSPHERE PURIFICATION AND CONTROL

How can understanding of atmospheric purification and control system technology benefit the development of life support and protective systems? What are the pertinent constituents of the cabin atmosphere, other than oxygen and diluents, that should be controlled?

(SEE CHART 1-23)

1.1.3.3 THERMAL CONTROL

How can the development and understanding of the thermal control system technology contribute to life support and protective systems?

(SEE CHART 1-24)

1.1.3.4 WATER MANAGEMENT

How can better understanding of water management system technology benefit life support and protective systems?

(SEE CHART 1-25)

1.1.3.5 WASTE MANAGEMENT

How can increased understanding of waste management system technology contribute to better life support and protective systems?

(SEE CHART 1-26)

1.1.3.6 FOOD MANAGEMENT

How can the development and better understanding of food management system technology enhance the capabilities of life support and technology systems? What are the basic approaches involved in spacecraft food mangement systems?

(SEE CHART 1-27)

1.1.3.7 CREW PROTECTIVE SYSTEMS

How can the development of crew protection system technology benefit life support and protective systems?

(SEE CHART 1-28)

1.1.3.8 INTEGRATED LIFE SUPPORT SYSTEMS

How can the development and better understanding of advanced integrated life support systems contribute to life support and protective systems technology?

(CRITICAL ISSUES IN TABLE 1)

(SEE CHART 1-1)

1.2 ENGINEERING EXPERIMENTS

How can the technology and equipment for spacecraft components and subsystems with which man interacts or which are required for manned spaceflight be experimentally evaluated?

1.2.1 DATA MANAGEMENT SUBSYSTEMS

How can advanced techniques, components, and subsystems for processing data on extended manned spaceflight be developed and evaluated?

(SEE CHART 1-42)

1.2.2 ELECTRICAL POWER

How can equipment for providing electrical power to advanced manned space vehicles and man's capability in operating, controlling, and maintaining such equipment be evaluated?

(SEE CHART 1-43)

1.2.3 STABILIZATION AND CONTROL

How can components, subsystems, and man-machine interfaces for stabilization and control of advanced manned space vehicles be evaluated?

(SEE CHART 1-44)

1.2.4 NAVIGATION AND GUIDANCE

How can man's knowledge about the feasibility and effectiveness of navigation and guidance techniques and equipment for advanced manned space vehicles be increased?

(SEE CHART 1-45)

1.2.5 COMMUNICATION SUBSYSTEMS

How can communications components and subsystems for applicability to advanced manned space vehicles be developed and evaluated?

(SEE CHART 1-46)

Chart 1-6. Manned Spaceflight Capability - Operations Experiments

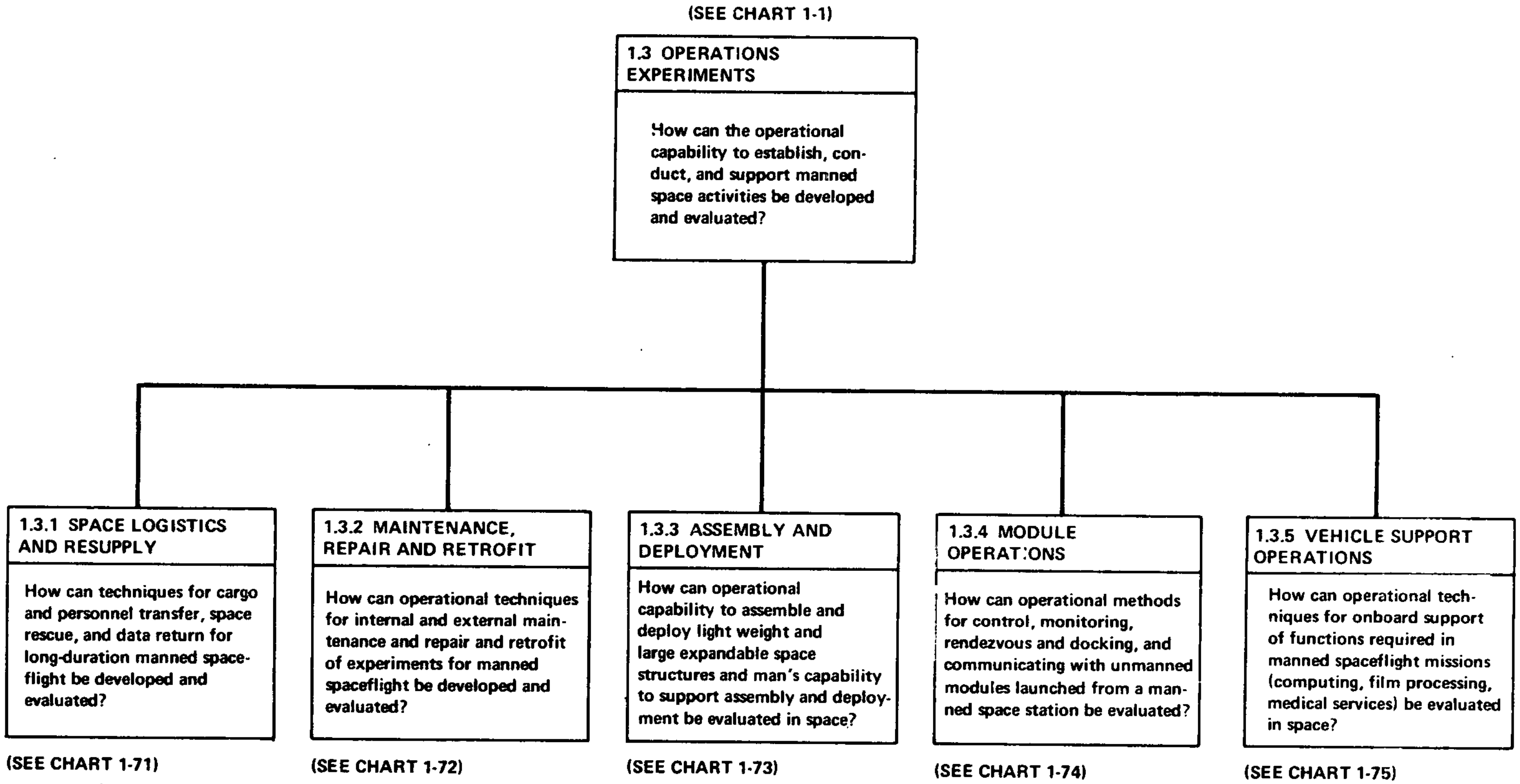


Chart 1-7. Manned Spaceflight Capability – Cardiovascular Changes

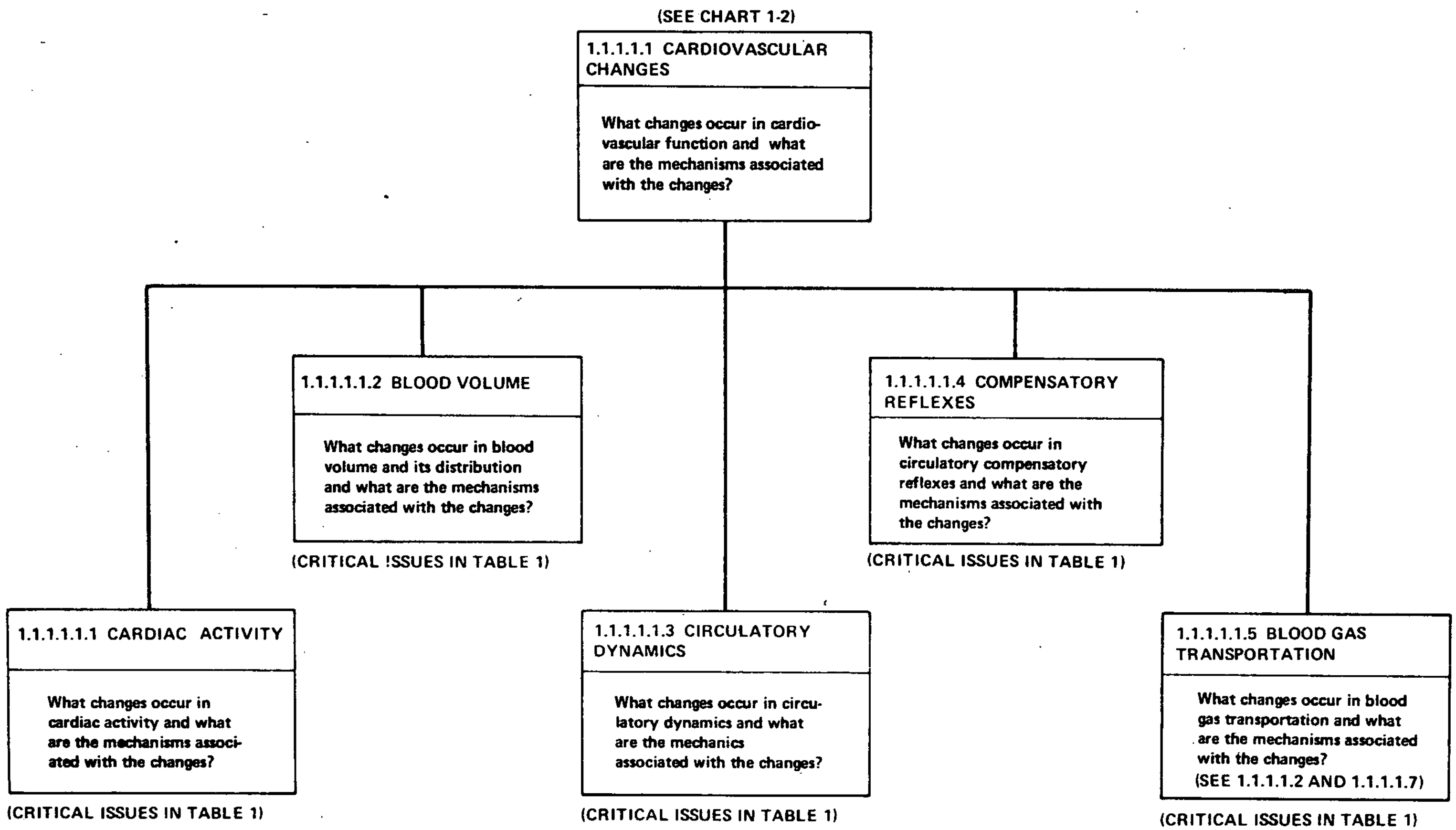


Chart 1-8. Manned Spaceflight Capability – Respiratory Changes

(SEE CHART 1-2)

1.1.1.1.2 RESPIRATORY CHANGES

What changes occur in respiratory function and what mechanisms are associated with the changes?

1.1.1.1.2.1 PULMONARY FUNCTION

What changes occur in pulmonary function and what mechanisms are associated with the changes?

(CRITICAL ISSUES IN TABLE 1)

1.1.1.1.2.2 GAS EXCHANGE AND TRANSPORTATION

What changes occur in respiratory gas exchange and transportation and what are the mechanisms associated with the changes?

(CRITICAL ISSUES IN TABLE 1)

1.1.1.1.2.3 RESPIRATORY CONTROL MECHANISMS

What changes occur in respiratory control and compensatory reflexes and what are the mechanisms associated with the changes?

(CRITICAL ISSUES IN TABLE 1)

1.1.1.1.2.4 CILIARY ACTIVITY

What changes occur in ciliary activity in the respiratory tract and what are the mechanisms associated with the changes?

(CRITICAL ISSUES IN TABLE 1)

Chart 1-9. Manned Spaceflight Capability - Neurological Changes

(SEE CHART 1-2)

1.1.1.1.3 NEUROLOGICAL CHANGES

What changes occur in neurological function and what are the mechanisms associated with the changes?

1.1.1.1.3.2 NERVE AND SYNOPES TRANSMISSION

What changes occur in nerve and synapse transmission and what are the mechanisms associated with the changes?

(CRITICAL ISSUES IN TABLE 1)

1.1.1.1.3.1 VESTIBULAR FUNCTION

What changes occur in vestibular function and what are the mechanisms associated with the changes?

1.1.1.1.3.1.1 OTOLITH ACTIVITIES

What changes occur in vestibular functions that originate in otolith activities and what are the associated mechanisms?

(CRITICAL ISSUES IN TABLE 1)

1.1.1.1.3.1.2 SEMICIRCULAR CANAL ACTIVITIES

What changes occur in vestibular functions that originate primarily in semicircular canal activities and what are the mechanisms associated with the changes?

(CRITICAL ISSUES IN TABLE 1)

1.1.1.1.3.3 ELECTROENCEPHALOGRAPH PATTERNS

What changes occur in electroencephalographic patterns and what are the mechanisms associated with the changes?

(CRITICAL ISSUES IN TABLE 1)

1.1.1.1.3.4 SENSORY FUNCTION

What changes occur in sensory function and what are the mechanisms associated with the changes?

(CRITICAL ISSUES IN TABLE 1)

1.1.1.1.3.5 MOTOR PERFORMANCE

What changes occur in motor performance and what are the mechanisms associated with the changes?

(CRITICAL ISSUES IN TABLE 1)

1.1.1.1.3.6 REFLEX ACTIVITY

What changes occur in reflex activity and what are the mechanisms associated with the changes?

1.1.1.1.3.6.1 SKELETAL MUSCLE REFLEXES

What changes occur in reflex activity associated with skelatal muscle responses and what are the mechanisms associated with the changes?

(CRITICAL ISSUES IN TABLE 1)

1.1.1.1.3.6.2 AUTONOMIC REFLEXES

What changes occur in autonomic reflexes and what are the mechanisms associated with the changes?

(CRITICAL ISSUES IN TABLE 1)

1.1.1.1.3.7 INTEGRATIVE AND COGNATIVE PROCESSES

What changes occur in integrative and cognative processes and what are the mechanisms associated with the changes?

(CRITICAL ISSUES IN TABLE 1)

(SEE CHART 1-2)

1.1.1.1.4 GASTRO-INTESTINAL FUNCTION

What changes occur in the gastrointestinal functions and what are the mechanisms associated with the changes?

1.1.1.1.4.1 MOTILITY

What changes occur in the gastrointestinal motility and what are the mechanisms associated with the changes?

(CRITICAL ISSUES IN TABLE 1)

1.1.1.1.4.2 SECRETORY PROCESS

What changes occur in the secretory processes and what are the mechanisms associated with the changes?

(CRITICAL ISSUES IN TAB TABLE 1)

1.1.1.1.4.3 DIGESTION

What changes occur in the digestive processes and what are the mechanisms associated with the changes?

(CRITICAL ISSUES IN TABLE 1)

1.1.1.1.4.4 ABSORPTION

What changes occur in the gastrointestinal absorption and what are the mechanisms associated with the changes?

(CRITICAL ISSUES IN TABLE 1)

1.1.1.1.4.5 BILE AND LIVER FUNCTION

What changes occur in the biliary and liver function and what are the mechanisms associated with the changes?

(CRITICAL ISSUES IN TABLE 1)

1.1.1.1.4.6 GAS FORMATION

What changes occur in the gas formation and management and what are the mechanisms associated with the changes?

(CRITICAL ISSUES IN TABLE 1)

1.1.1.1.4.7 FECAL MANAGEMENT

What changes occur in the fecal management and what are the mechanisms associated with the changes?

(CRITICAL ISSUES IN TABLE 1)

1.1.1.1.4.8 HUNGER AND THIRST

What changes occur in the control of hunger and thirst and what are the mechanisms associated with the changes?

(CRITICAL ISSUES IN TABLE 1)

Chart 1-11. Manned Spaceflight Capability – Excretory Function and Fluid Balance

(SEE CHART 1-2)

1.1.1.1.5 EXCRETORY FUNCTION AND FLUID BALANCE

What changes occur in the excretory function and fluid balance and what are the mechanisms associated with the changes?

- **1.1.1.1.5.1 KIDNEY FUNCTION**

  What changes occur in the normal kidney function and what are the mechanisms associated with the changes?

  (CRITICAL ISSUES IN TABLE 1)

- **1.1.1.1.5.2 URINE**

  What changes occur in the volume and composition of urine and how are they related to changes in body fluid and electrolyte balance?

  (CRITICAL ISSUES IN TABLE 1)

- **1.1.1.1.5.3 BLADDER CONTROL**

  What changes occur in bladder control and micturition and how will the changes affect waste management procedure? agement procedures?

  (CRITICAL ISSUES IN TABLE 1)

- **1.1.1.1.5.4 HYDRATION**

  What effects will changes in excretory function have on total body hydration and what is the nature of the changes?

  (CRITICAL ISSUES IN TABLE 1)

- **1.1.1.1.5.5 PH OF BODY FLUIDS**

  What effects will changes in excretory function have on the pH of body fluids and what is the nature of the changes?

  (CRITICAL ISSUES IN TABLE 1)

- **1.1.1.1.5.6 ELECTROLYTE CONTENT**

  What effects will changes in excretory function have on the electrolyte content of body fluids and what is the nature of the changes?

  (CRITICAL ISSUES IN TABLE 1)

Chart 1-12. Manned Spaceflight Capability -
Metabolic and Musculo Skeletal Function

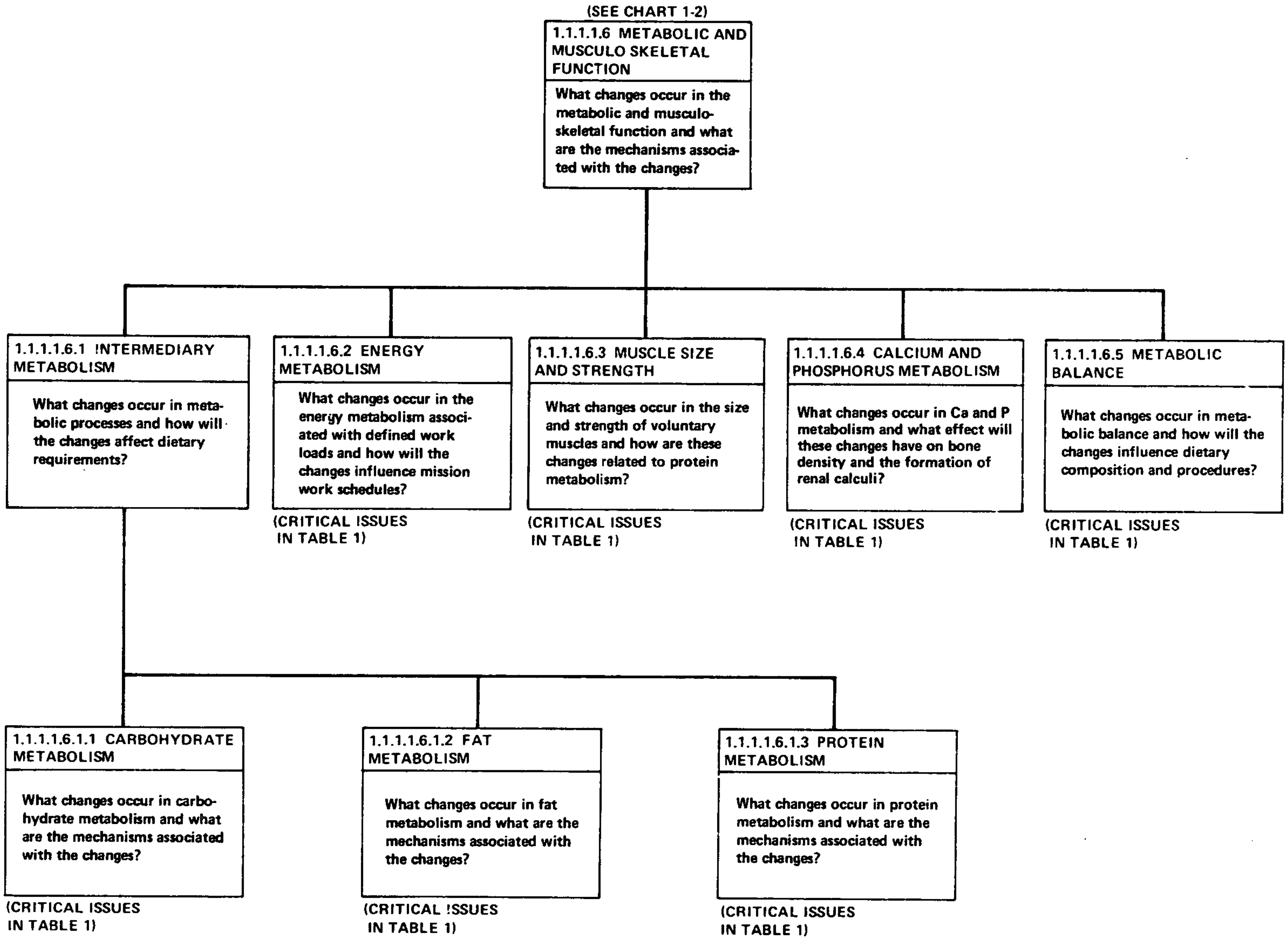


Chart 1-13. Manned Spaceflight Capability – Hematology and Immunology

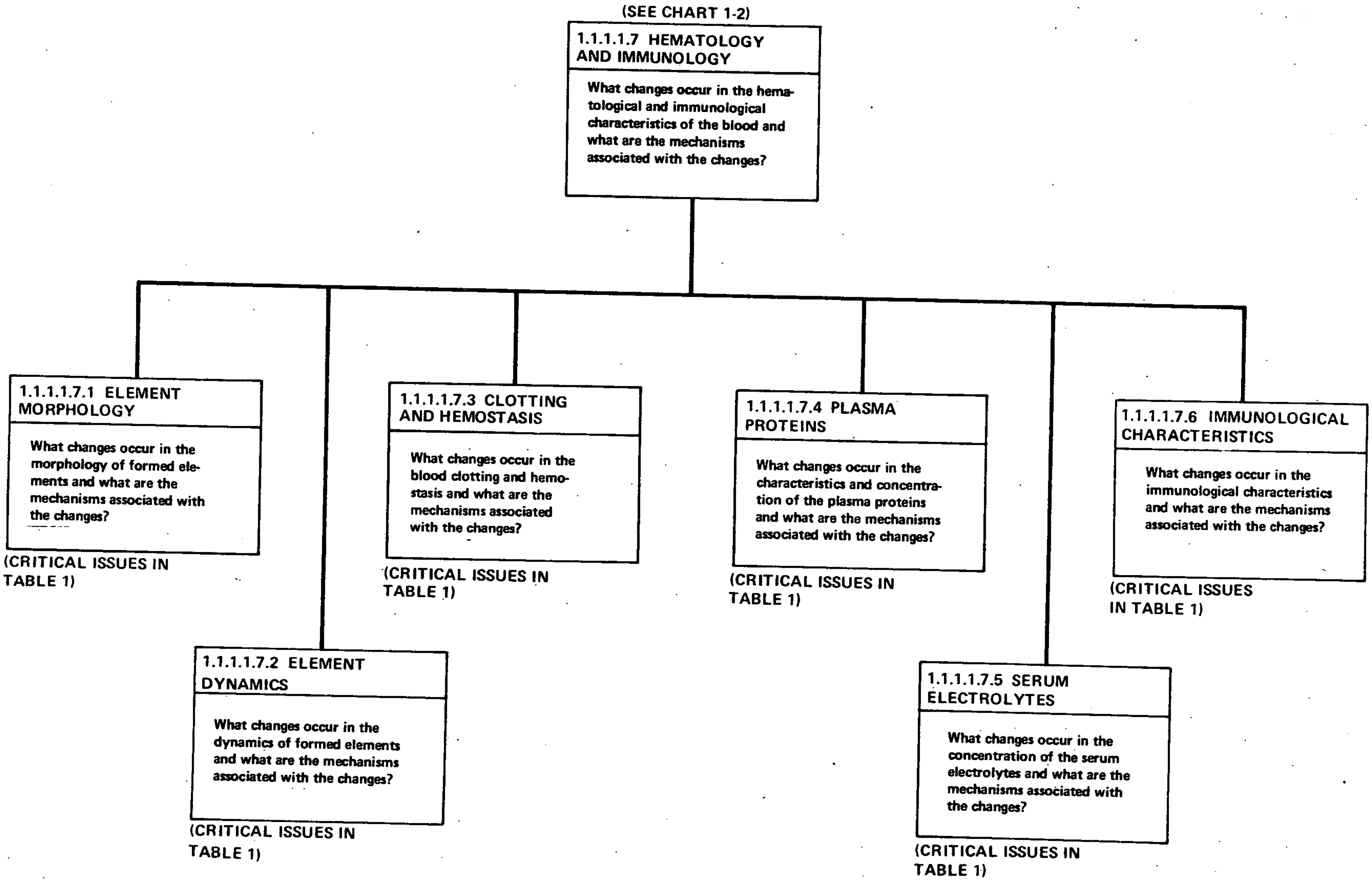


Chart 1-14. Manned Spaceflight Capability - Endocrine Function

(SEE CHART 1-2)

1.1.1.1.8 ENDOCRINE FUNCTION

What changes occur in endocrine function and what are the mechanisms associated with the change?

- **1.1.1.1.8.1 HORMONE SYNTHESIS**

  What changes occur in hormone synthesis and release and what are the mechanisms associated with the change?

  (CRITICAL ISSUES IN TABLE 1)

- **1.1.1.1.8.2 HORMONE EFFECTS**

  What changes occur in effects that hormones have on target tissues and what are the mechanisms associated with the change?

  (CRITICAL ISSUES IN TABLE 1)

- **1.1.1.1.8.3 CONTROL AND REGULATION**

  What changes occur in control and regulation of endocrine function and what are the mechanisms associated with the change?

  (CRITICAL ISSUES IN TABLE 1)

Chart 1-15. Manned Spaceflight Capability – Medical Problems

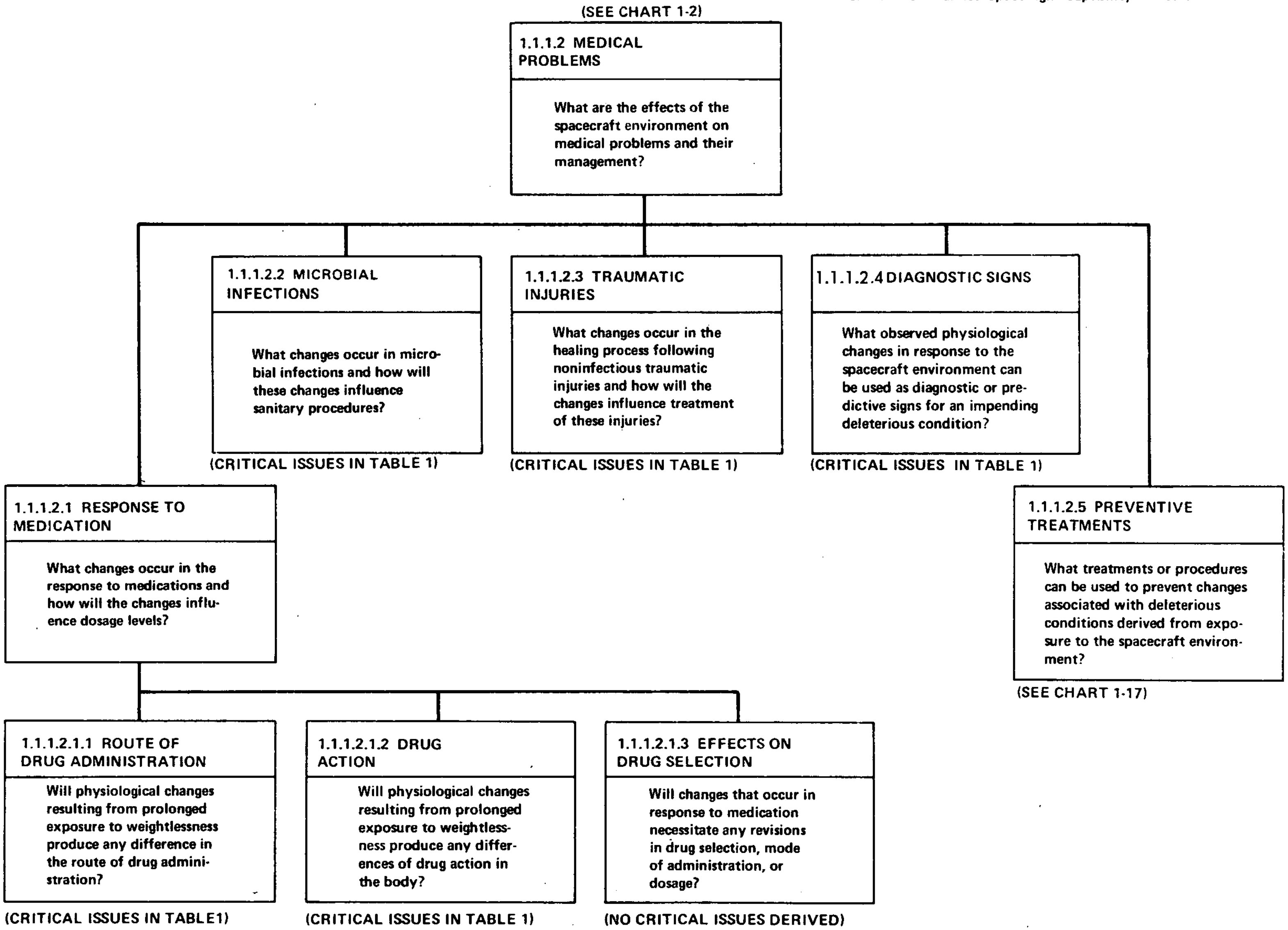


Chart 1-16. Manned Spaceflight Capability - Stress Tolerance Changes

(SEE CHART 1-2)

1.1.1.3 STRESS TOLERANCE CHANGES
What changes occur in the tolerance limits to potential environmental stresses due to prolonged exposure to the spacecraft environment and how will these changes affect environmental control criteria?

- **1.1.1.3.1 TOLERANCE TO REDUCED OXYGEN**
  What changes occur in response and tolerance to reduced oxygen pressure in the spacecraft environment and how will the changes influence the definition of the spacecraft atmosphere?
  - **1.1.1.3.1.1 NEUROLOGICAL EFFECTS**
    What changes occur in the effects of hypoxia on the nervous system and what are the mechanisms associated with the changes?
    (CRITICAL ISSUES IN TABLE 1)
  - **1.1.1.3.1.2 CARDIOVASCULAR EFFECTS**
    What changes occur in the response of the cardiovascular system to hypoxia and what are the mechanisms associated with the changes?
    (CRITICAL ISSUES IN TABLE 1)
  - **1.1.1.3.1.3 RESPIRATORY EFFECTS**
    What changes occur in the response of the respiratory system to hypoxia and what are the mechanisms associated with the changes?
    (CRITICAL ISSUES IN TABLE 1)
  - **1.1.1.3.1.4 HEMATOLOGICAL CHARACTERISTICS**
    What changes occur in the effects of hypoxia on hematological characteristics and what are the mechanisms associated with the changes?
    (CRITICAL ISSUES IN TABLE 1)
  - **1.1.3.1.5 OTHER EFFECTS**
    What other effects must be considered with regard to hypoxia?
    (CRITICAL ISSUES IN TABLE 1)
- **1.1.1.3.2 TOLERANCE TO INCREASED CO_2**
  What changes occur in response and tolerance to increased carbon dioxide pressures in the spacecraft environment and how will the changes influence allowable carbon dioxide levels in the spacecraft atmosphere.
  (CRITICAL ISSUES IN TABLE 1)
- **1.1.1.3.3 TOLERANCE TO DILUENT GAS EFFECTS**
  What effect will changes in the type and pressure of diluent gas have on respiratory phenomena and tolerance to envolved gas dysbarism and how will these changes influence spacecraft atmosphere composition?
  (CRITICAL ISSUES IN TABLE 1)
- **1.1.1.3.4 ACCELERATION TOLERANCE**
  What changes occur in response and tolerance to acceleration and how will the changes affect mission procedures related to the application of acceleration or gravitation?
  (CRITICAL ISSUES IN TABLE 1)
- **1.1.1.3.5 TOLERANCE TO TEMPERATURE VARIATIONS**
  What changes occur in response and tolerance to environmental temperature variations and how will the changes influence the definition of the spacecraft thermal environment
  - **1.1.1.3.5.1 ELEVATED TEMPERATURES**
    What changes occur in response and tolerance to elevated environmental temperatures and what are the mechanisms associated with the changes?
    (CRITICAL ISSUES IN TABLE 1)
  - **1.1.3.5.2 DEPRESSED TEMPERATURES**
    What changes occur in response and tolerance to depressed environmental temperature and what are the mechanisms associated with the changes?
    (CRITICAL ISSUES IN TABLE 1)
- **1.1.1.3.6 EXERCISE TOLERANCE**
  What changes occur in response and tolerance to strenuous exercise and how will the changes affect work load schedules during the mission?
  (CRITICAL ISSUES IN TABLE 1)
- **1.1.1.3.7 RADIATION TOLERANCE**
  What changes occur in tolerance to radiation and how will the changes influence the definition of radiation protective measures for the spacecraft?
  (CRITICAL ISSUES IN TABLE 1)
- **1.1.1.3.8 TOLERANCE TO TOXIC CONTAMINANTS**
  What changes occur in the tolerance to toxic contaminants in the spacecraft atmosphere and how will the changes influence allowable concentration levels for various contaminants?
  (CRITICAL ISSUES IN TABLE 1)
- **1.1.1.3.9 TOLERANCE TO NOISE AND VIBRATION**
  What changes occur in tolerance to noise and vibration within the spacecraft and how will the change influence allowable limits for noise and vibration?
  (NO CRITICAL ISSUES DERIVED)

Chart 1-17. Manned Spaceflight Capability - Preventive Treatments

(SEE CHART 1-15)

1.1.1.2.5 PREVENTIVE TREATMENTS

What treatments or procedures can be used to prevent changes associated with deleterious conditions derived from exposure to the spacecraft environment?

1.1.1.2.5.7 REVERSAL OF CHANGE

Can any of the measures found effective in preventing the occurrence of deleterious biomedical changes be used to reverse the biomedical change if it has already occurred?

(NO CRITICAL ISSUES DERIVED)

1.1.1.2.5.6 STRESS ACCLIMATIZATION

Can the biomedical changes that are produced by chronic adaptation to an environmental stress offset the occurrence of deleterious biomedical changes?

(CRITICAL ISSUES IN TABLE 1)

1.1.1.2.5.5 DRUG ADMINISTRATION

Can the administration of drugs or chemicals prevent the occurrence of deleterious biomedical changes?

(NO CRITICAL ISSUES DERIVED)

1.1.1.2.5.4 REDISTRIBUTION OF BLOOD VOLUME

Can a periodic redistribution of blood volume by devices, such as the lower body negative pressure device and occlusive garments or cuffs or by increasing intrathoracic pressure, be used to prevent cardiovascular deconditioning?

(NO CRITICAL ISSUES DERIVED)

1.1.1.2.5.1 ARTIFICIAL GRAVITY

Can artificial gravity derived from rotating the spacecraft be used to prevent the occurrence of deleterious biomedical changes?

(CRITICAL ISSUES IN TABLE 1)

1.1.1.2.5.2 EXERCISE

Can an exercise program be used to prevent the occurrence of deleterious biomedical changes?

(CRITICAL ISSUES IN TABLE 1)

1.1.1.2.5.3 CENTRIFUGATION

Can centrifugation by means of manned onboard centrifuge be used to prevent the occurrence of deleterious biomedical changes?

(CRITICAL ISSUES IN TABLE 1)

Chart 1-18. Manned Spaceflight Capability - Individual Behavioral Research

(SEE CHART 1-3)

1.1.2.1.1 INDIVIDUAL BEHAVIORAL RESEARCH

What is the influence of long-duration spaceflight on individual behavior?

1.1.2.1.1.1 SENSORY

What is the influence of long-duration spaceflight on human sensory functions?

(SEE CHART 1-19)

1.1.2.1.1.2 PSYCHOMOTOR

What is the effect of long-duration spaceflight on human psychomotor functions with respect to perceptual motor functions, manipulation and control, and force production and control?

(CRITICAL ISSUES IN TABLE 1)

1.1.2.1.1.3 COGNITIVE

What is the effect of long-duration spaceflight on human cognitive function?

(CRITICAL ISSUES IN TABLE 1)

Chart 1-19. Manned Spaceflight Capability - Sensory Influence

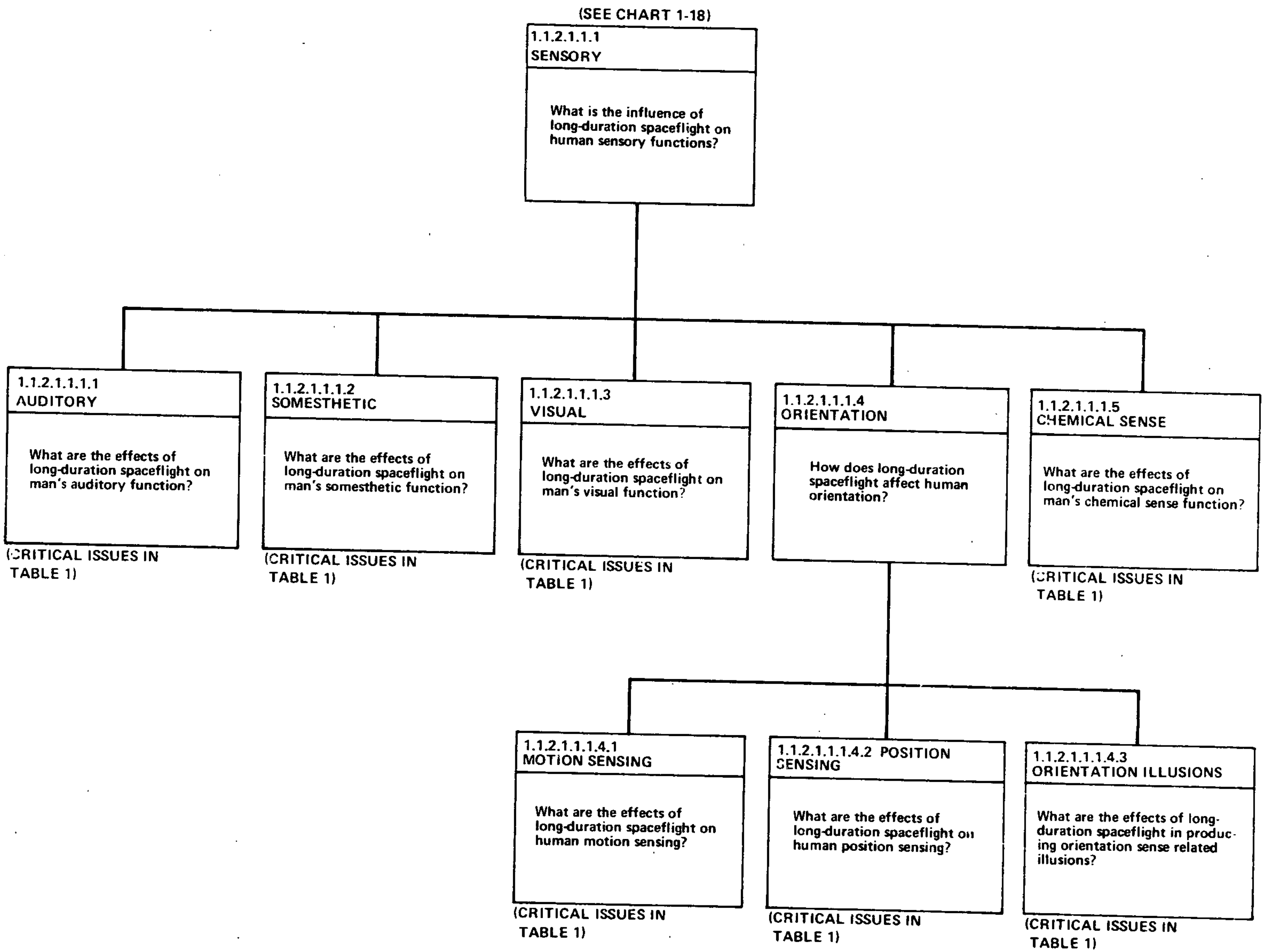


Chart 1-20. Manned Spaceflight Capability - Habitability and Activity Cycles

(SEE CHART 1-3)

1.1.2.2.3 HABITABILITY

How can methods, technology, and equipment for habitable living and working areas in long-duration space missions be developed and evaluated?

1.1.2.2.3.1 SPACE

How can man's understanding of astronaut space requirements for long-duration space flight (e.g., volume, configuration, living space, privacy) be increased?

(CRITICAL ISSUES IN TABLE 1)

1.1.2.2.3.2 ENVIRONMENT

How can man's understanding of the environmental requirements, limitations, and constraints for long-duration space missions (e.g., illumination, noise, temperature, decor, color) be increased?

(CRITICAL ISSUES IN TABLE 1)

1.1.2.2.3.3 PERSONAL SUPPORT

How can man's understanding of the personal support needs (e.g., hygiene, nutrition, recreation, sleep stations, maintenance of health) of astronauts on long-duration space missions be increased?

(CRITICAL ISSUES IN TABLE 1)

(SEE CHART 1-3)

1.1.2.2.4 WORK/REST/ SLEEP CYCLES

How can man's understanding of circadian rhythms and diurnal cycles in space be increased and how can optimum work/rest/ sleep cycles for long-duration space missions be developed and evaluated?

1.1.2.2.4.1 RHYTHMS AND CYCLES

How can man's understanding of circadian rhythms and diurnal cycles in long-duration space flight be increased?

(CRITICAL ISSUES IN TABLE 1)

1.1.2.2.4.2 SLEEP

How can man's understanding of sleep requirements and sleep behavior (e.g., duration, depth, susceptibility to external effects, movement) in long-duration space flight be increased?

(CRITICAL ISSUES IN TABLE 1)

1.1.2.2.4.3 WORK/REST

How can man's understanding of optimum work/rest cycles in long-duration space flight be increased?

(CRITICAL ISSUES IN TABLE 1)

Chart 1-21. Manned Spaceflight Capability - Performance Aids

(SEE CHART 1-3)

1.1.2.2.5 PERFORMANCE AIDS

How can we identify, develop and evaluate aids for enhancement of human performance in long-duration space missions?

1.1.2.2.5.1 TOOLS

What are the new or improved tools required in long-duration space flights for maintenance and operational functions and how can they be developed and evaluated?

(CRITICAL ISSUES IN TABLE 1)

1.1.2.2.5.2 MANIPULATORS AND FORCE ASSISTIVE DEVICES

Under what conditions in long duration space flight will manipulators and servos be required to enhance human performance and how can they be developed?

(CRITICAL ISSUES IN TABLE 1)

1.1.2.2.5.3 COMPUTER AIDS AND CHECKLISTS

How can computers and checklists be used to enhance human performance in long-duration space flight?

(CRITICAL ISSUES IN TABLE 1)

Chart 1-22. Manned Spaceflight Capability – Atmosphere Supply

(SEE CHART 1-4)

1.1.3.1 DEVELOPMENT OF ATMOSPHERIC SUPPLY AND PRESSURIZATION SYSTEM TECHNOLOGY

How can the development and understanding of atmospheric supply and pressurization system contribute to life support and protective systems and what are the pertinent functions performed by the atmospheric supply and pressurization system?

- **1.1.3.1.1 ATMOSPHERE SUPPLY**

  What are the various approaches used in the supply of oxygen and diluent gases to the spacecraft cabin?

  - **1.1.3.1.1.1 STORAGE OF GASES**

    What are the processes used in the storage of gases and what are their potential uses and effects on the crew, spacecraft and subsystems?

    - **1.1.3.1.1.1.1 CHEMICAL**

      What are the aspects of atmosphere storage by chemical methods and what are the conceptual configurations considered?

      (CRITICAL ISSUES IN TABLE 1)

    - **1.1.3.1.1.1.2 GASEOUS**

      What are the aspects of atmosphere storage by gaseous methods and what are the conceptual configurations considered?

      (CRITICAL ISSUES IN TABLE 1)

    - **1.1.3.1.1.1.3 CRYOGENIC STORAGE**

      What are the aspects of atmosphere storage by cryogenic methods and what are the conceptual configurations considered?

      (CRITICAL ISSUES IN TABLE 1)

  - **1.1.3.1.1.2 OXYGEN AND DILUENT SUPPLY**

    What are the various approaches of supply of oxygen and diluents to the spacecraft cabin atmosphere?

    (SEE CHART 1-29)

- **1.1.3.1.2 CABIN ATMOSPHERE PRESSURE CONTROL**

  What types of pressure control systems are considered?

  (SEE CHART 1-30)

Chart 1-23. Manned Spaceflight Capability – Atmosphere Purification and Control

(SEE CHART 1-4)

1.1.3.2 ATMOSPHERIC PURIFICATION AND CONTROL

How can understanding of atmospheric purification and control system technology benefit the development of life support and protective systems?

1.1.3.2.1 CARBON DIOXIDE

What are the methods of controlling the CO_2 concentration in the cabin atmosphere?

(SEE CHART 1-31)

1.1.3.2.2 TRACE CONTAMINANTS

What are the means of detecting, identifying, and controlling trace contaminants in spacecraft atmosphere and what are their implications?

(SEE CHART 1-32)

1.1.3.2.3 HUMIDITY

What are the means of controlling humidity in spacecraft atmosphere and what are their implications?

(SEE CHART 1-33)

1.1.3.2.4 AEROSOLS

What are the means of detecing, identifying, and controlling aerosols in spacecraft atmosphere and what are their implications?

(SEE CHART 1-34)

Chart 1-24. Manned Spaceflight Capability - Thermal Control

(SEE CHART 1-4)

- **1.1.3.3 THERMAL CONTROL**
  How can the development and understanding of the thermal control system technology contribute to life support and protective systems?
  - **1.1.3.3.1 PASSIVE THERMAL CONTROL**
    What are the various approaches involved in the passive thermal control of spacecraft and what are their potential uses and effects on the crew, spacecraft and life support and other subsystems?
    - **1.1.3.3.1.1 INSULATION**
      What are the processes involved in passive thermal control of spacecraft by the use of insulation and what are their potential uses and effects on the crew, spacecraft and life support and other subsystems?
      (SEE CHART 1-35)
    - **1.1.3.3.1.2 RADIATIVE SURFACES**
      What are the processes involved in passive thermal control of space cabins by the use of radiative surfaces and what are their potential uses and effects on the crew, spacecraft and life support and other subsystems?
      (SEE CHART 1-35)
    - **1.1.3.3.1.1.3 HEAT PIPES**
      What are the processes involved in passive thermal control of spacecraft by the use of heat pipes and what are their potential uses and effects on the crew, spacecraft and subsystems?
      (CRITICAL ISSUES IN TABLE 1)
  - **1.1.3.3.2 ACTIVE THERMAL CONTROL**
    What are the various approaches involved in the active thermal control of spacecraft and what are their potential uses and effects on the crew, spacecraft and life support and other subsystems?
    - **1.1.3.3.2.1 HEATING SYSTEMS**
      What are the basic approaches used in heating of spacecraft and should they be investigated under space flight conditions?
      (SEE CHART 1-36)
    - **1.1.3.3.2.2 COOLING SYSTEMS**
      What are the basic approaches used in cooling of spacecraft and should they be investigated under space flight conditions?
      (SEE CHART 1-37)

Chart 1-25. Manned Spaceflight Capability - Water Management

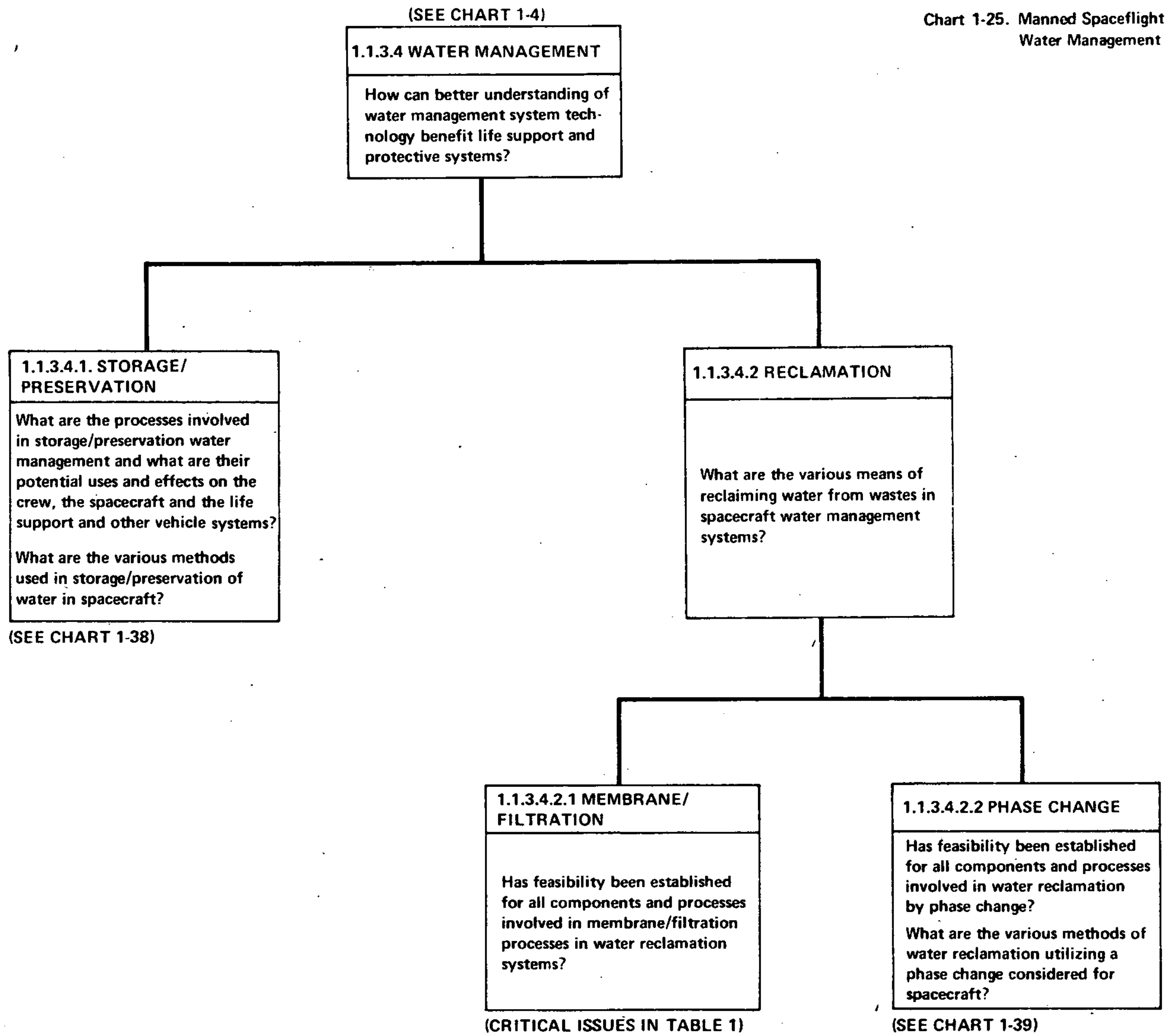


Chart 1-26. Manned Spaceflight capability – Waste Management

(SEE CHART 1-4)

1.1.3.5 WASTE MANAGEMENT

How can increased understanding of waste management system technology contribute to better life support and protective systems?

- **1.1.3.2.1 COLLECTION** — What are the various methods of collection of waste management and what are their classifications and application effect?
  - **1.1.3.5.1.1 URINE** — What are the aspects of urine collection in spacecraft waste management systems and what are the conceptual configurations considered? (CRITICAL ISSUES IN TABLE 1)
  - **1.1.3.5.1.2 FECES/REFUSE** — What are the aspects of feces and/or refuse collection and what are the conceptual configurations considered? (CRITICAL ISSUES IN TABLE 1)
- **1.1.3.5.2 INCINERATION** — What are the aspects of incinerating urine residue, feces and/or refuse and what are their conceptual configurations considered? (CRITICAL ISSUES IN TABLE 1)
- **1.1.3.5.3 STORAGE** — What are the various methods of storing waste matter and what are their classifications and application effect?
  - **1.1.3.5.3.1 URINE** — What are the aspects of urine storage in spacecraft waste management systems and what are the conceptual configurations considered? (CRITICAL ISSUES IN TABLE 1)
  - **1.1.3.5.3.2 FECES/REFUSE** — What are the aspects of feces and/or refuse storage and what are the conceptual configurations considered? (CRITICAL ISSUES IN TABLE 1)
- **1.1.3.5.4 RECOVERY** — What are the waste management reclamation processes considered and what are their potential uses and effects on the crew, spacecraft and life support and other subsystems? (SEE CHART 1-40)
- **1.1.3.5.5 DUMP** — What are the various methods of dumping waste management and what are their classifications and application effect?
  - **1.1.3.5.5.1 URINE** — What are the aspects of urine dump in spacecraft waste management systems and what are the conceptual configurations considered? (NO CRITICAL ISSUES DERIVED)
  - **1.1.3.5.5.2 FECES/REFUSE** — What are the aspects of feces and/or refuse dump and what are the conceptual configurations considered? (NO CRITICAL ISSUES DERIVED)

Chart 1-27. Manned Spaceflight Capability — Food Management

(SEE CHART 1-4)

1.1.3.6 FOOD MANAGEMENT

How can the development and better understanding of food management system technology enhance the capabilities of life support and protective systems?

What are the basic approaches involved in spacecraft food management systems?

- **1.1.3.6.1 STORED FOOD**

  What are the processes involved in stored food management and what are their potential uses and effects on the crew, spacecraft, and other subsystems?

  - **1.1.3.6.1.1 FREEZE-DRIED**

    What are the aspects of stored food management by freeze-drying and what are the conceptual configurations considered?

    (CRITICAL ISSUES IN TABLE 1)

  - **1.1.3.6.1.2 FROZEN**

    What are the processes involved in stored food management utilizing frozen food and what are their potential uses and effects on the crew, spacecraft and life support and other subsystems?

    (CRITICAL ISSUES IN TABLE 1)

  - **1.1.3.6.1.3 IRRADIATED/CANNED**

    What are the processes involved in stored food management utilizing irradiated food and what are their potential uses and effects on the crew, spacecraft and life support and other subsystems?

    (CRITICAL ISSUES IN TABLE 1)

- **1.1.3.6.2 REGENERATIVE**

  What are the regenerative processes involved in food management systems and what are their potential uses and effects on the crew, spacecraft and life support and other subsystems?

  - **1.1.3.6.2.1 CHEMICAL SYNTHESIS**

    What are the aspects of food regeneration by chemical synthesis and what are the conceptual configurations considered?

    (CRITICAL ISSUES IN TABLE 1)

  - **1.1.3.6.2.2 BIOLOGICAL REGENERATION**

    What are the aspects of food regeneration from metabolic wastes by biological processes and what are the conceptual configurations considered?

    (CRITICAL ISSUES IN TABLE 1)

Chart 1-28. Manned Spaceflight Capability – Crew Protective Systems

(SEE CHART 1-4)

- **1.1.3.7 CREW PROTECTION SYSTEM**
  How can the development of crew protection system technology benefit lift support and protective systems?
  - **1.1.3.7.1 INTERNAL HAZARDS**
    What hazards, inside the spacecraft, require the use of crew protection systems?
    - **1.1.3.7.1.1 FIRE**
      What are the various methods of crew protection from fires inside the spacecraft and what are their classifications and application effects?
      (CRITICAL ISSUES IN TABLE 1)
    - **1.1.3.7.1.2 ATMOSPHERE CONTAMINANTS CONTROL**
      What are the various methods of atmospheric contaminants control and what are their classifications and application effects?
      (SEE CHART 1-41)
    - **1.1.3.7.1.3 THERMAL PROTECTION**
      What are the processes involved in the protection of the crew against the thermal environment inside the spacecraft and what are their potential uses and effects on the crew, spacecraft and life support and other subsystems?
      (REFER TO CHART 1-24)
    - **1.1.3.7.1.4 BIOLOGICAL CONTROL**
      What are the processes involved in the protection of the crew against biological hazards?
      What are the various methods of crew protection against biological hazards and what are their classifications and application effects?
      (CRITICAL ISSUES IN TABLE 1)
  - **1.1.3.7.2 EXTERNAL HAZARDS**
    What hazards, external to the spacecraft, require the use of crew protection systems?
    - **1.1.3.7.2.1 ZERO GRAVITY**
      What are the various methods of crew protection against zero gravity effects and what are their classifications and application effects?
      (CRITICAL ISSUES IN TABLE 1)
    - **1.1.3.7.2.2 RADIATION**
      What are the various methods of crew protection against space radiation hazards and what are their classifications and application effects?
      (CRITICAL ISSUES IN TABLE 1)
    - **1.1.3.7.2.3 METEOROIDS**
      What are the various methods of crew protection against meteoroid hazards and what are their classifications and application effect?
      (CRITICAL ISSUES IN TABLE 1)
    - **1.1.3.7.2.4 VACUUM**
      What are the various methods of crew protection against space vacuum and what are their classifications and application effects?
      (CRITICAL ISSUES IN TABLE 1)

Chart 1-29. Manned Spaceflight Capability – Oxygen and Diluent Supply

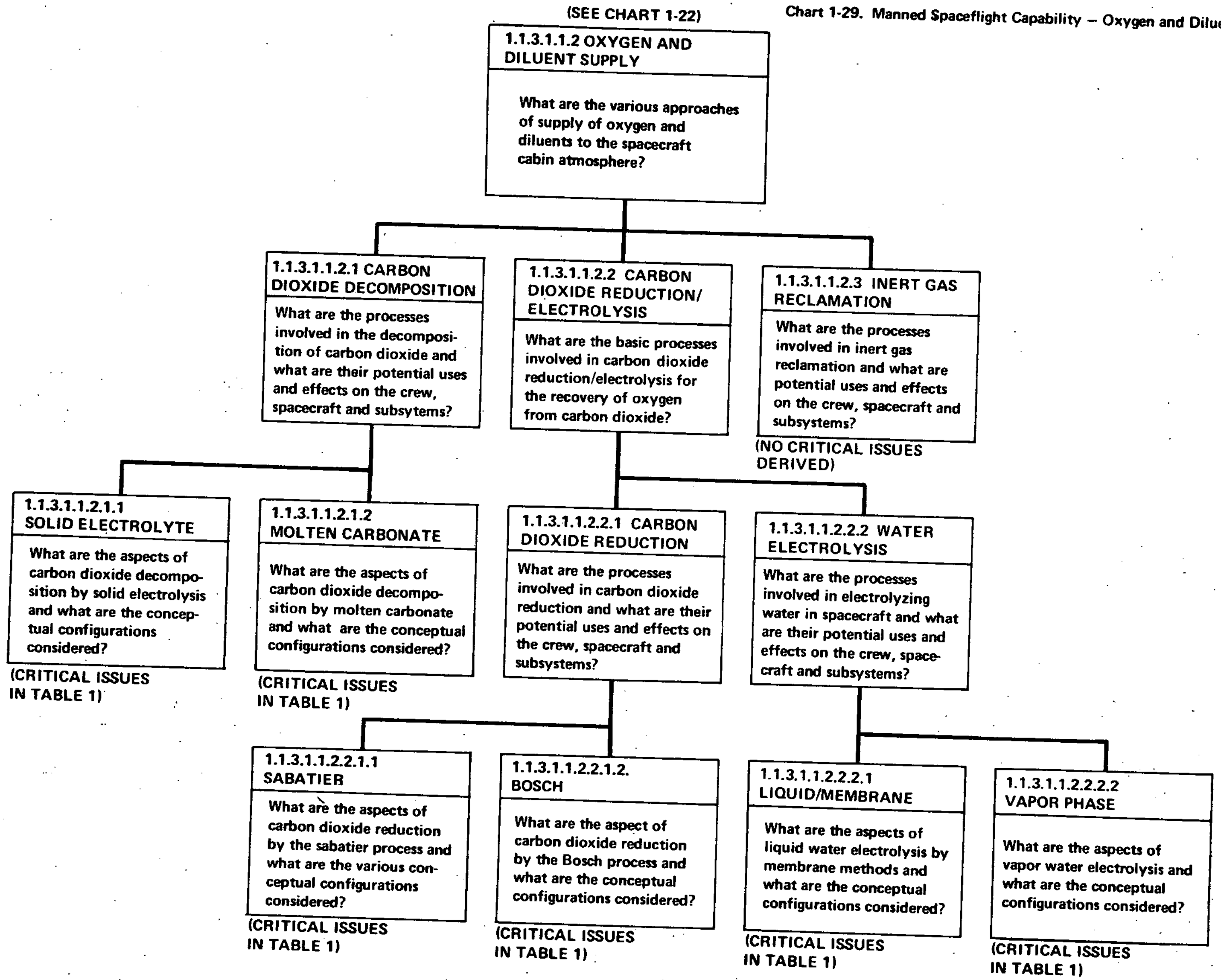


Chart 1-30. Manned Spaceflight Capability - Cabin Atmosphere Pressure Control

(SEE CHART 1-22)

1.1.3.1.2
CABIN ATMOSPHERE PRESSURE CONTROL

What types of pressure control systems are considered?

1.1.3.1.2.1
SINGLE GAS ATMOSPHERE PRESSURE CONTROL SYSTEM

What are the processes involved in single gas atmosphere pressure control systems and what are their potential uses and effects on the crew, spacecraft and life support and other subsystems?

(NO CRITICAL ISSUES DERIVED)

1.1.3.1.2.2
DUAL GAS ATMOSPHERE PRESSURE CONTROL SYSTEM

What are the processes involved in dual gas atmosphere pressure control systems and what are their potential uses and effects on the crew, spacecraft and life support and other subsystems?

(CRITICAL ISSUES IN TABLE 1)

Chart 1-31. Manned Spaceflight Capability - Carbon Dioxide

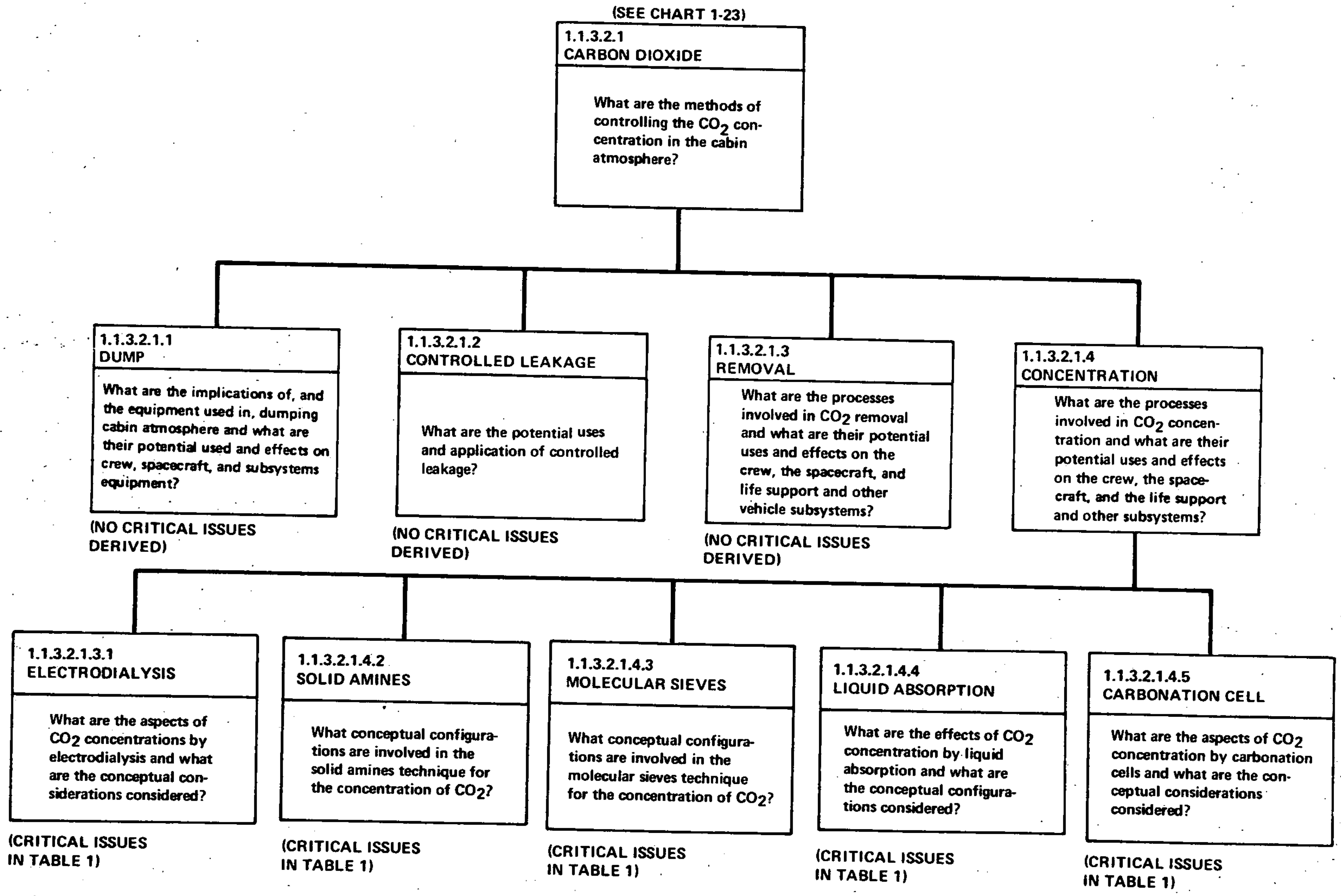


Chart 1-32. Manned Spaceflight Capability – Trace Contaminants

(SEE CHART 1-23)

1.1.3.2.2 TRACE CONTAMINANTS

What are the means of detecting, identifying, and controlling trace contaminants in spacecraft atmosphere and what are their implications?

1.1.3.2.2.1 DUMP

What are the implications and the equipment used in dumping cabin atmosphere and what are their potential uses and effects on crew, spacecraft and subsystems equipment?

(NO CRITICAL ISSUES DERIVED)

1.1.3.2.2.2 CONTROLLED LEAKAGE

What are the potential uses and application of controlled leakage?

(NO CRITICAL ISSUES DERIVED)

1.1.3.2.2.3 REMOVAL

What are the various methods of trace contaminants control and what are their application effects?

(CRITICAL ISSUES IN TABLE 1)

1.1.3.2.2.4 CATALYTIC OXIDATION

What are the various methods catalytic oxidation of trace contaminants and what are their classifications and application effects?

(CRITICAL ISSUES IN TABLE 1)

Chart 1-33. Manned Spaceflight Capability – Humidity

(SEE CHART 1-23)

- **1.1.3.2.3 HUMIDITY**
  What are the means of controlling humidity in spacecraft atmosphere and what are their implications?
  - **1.1.3.2.3.1.1 DUMP**
    What are the implications and the equipment used in dumping cabin atmosphere and what are their potential uses and effects on crew, spacecraft and subsystems equipment.
    (NO CRITICAL ISSUES DERIVED)
  - **1.1.3.2.3.2 CONTROLLED LEAKAGE**
    What are the potential uses and application of controlled leakage?
    (NO CRITICAL ISSUES DERIVED)
  - **1.1.3.2.3.3 CONDENSATION/ SEPARATION**
    What are the various methods of humidity control by condensation/ separation and what are their classifications and application effects?
    - **1.1.3.2.3.3.1 CONDENSATION**
      Reference Cooling/ Condensation
      (NO CRITICAL ISSUES DERIVED)
    - **1.1.3.2.3.3.2 SEPARATION**
      What are the aspects of humidity control by separation of water from gases and what are the conceptual configurations considered?
      (CRITICAL ISSUES IN TABLE 1)
  - **1.1.3.2.3.4 REMOVAL**
    Reference CO_2 control by removal. Different sorbers are used for water. Included are silica gel, molecular sieves, activated alumina, barium oxide, magnesium perchlorate, drierite and calium oxide.
    (NO CRITICAL ISSUES DERIVED)

Chart 1-34. Manned Spaceflight Capability – Aerosols

(SEE CHART 1-23)

1.1.3.2.4 AEROSOLS

What are the means of detecting, identifying, and controlling aerosols in spacecraft atmosphere and what are their implications?

- **1.1.3.2.4.1 DUMP**
  What are the implications and the equipment used in dumping cabin atmosphere and what are their potential uses and effects on crew, spacecraft and subsystems?
  (NO CRITICAL ISSUES DERIVED)

- **1.1.3.2.4.2 REMOVAL**
  What are the various methods used in controlling aerosols in the spacecraft atmosphere and what are their potential implications?

  - **1.1.3.2.4.2.1 FILTRATION**
    What are the aspects of aerosol control by filtration and what are the conceptual configurations considered?
    (CRITICAL ISSUES IN TABLE 1)

  - **1.1.3.2.4.2.2 PRECIPITATION**
    What are the aspects of aerosol control by precipitation and what are the conceptual configurations considered?
    (CRITICAL ISSUES IN TABLE 1)

  - **1.1.3.2.4.2.3 CENTRIFUGATION**
    What are the aspects of aerosol control by centrifugation and what are the conceptual configurations considered?
    (CRITICAL ISSUES IN TABLE 1)

  - **1.1.3.2.4.2.4 OTHER LIFE SUPPORT COMPONENTS**
    Reference trace contaminants, humidity and/or CO_2 removal subsystems for removal of aerosols.
    (NO CRITICAL ISSUES DERIVED)

- **1.1.3.2.4.3 CONTROLLED LEAKAGE**
  What are the potential uses and application of controlled leakage?
  (NO CRITICAL ISSUES DERIVED)

Chart 1-35. Manned Spaceflight Capability — Insulation and Radiative Surfaces

(SEE CHART 1-24)

1.1.3.3.1.1
INSULATION

What are the processes involved in passive thermal control of spacecraft by the use of insulation and what are their potential uses and effects on the crew, spacecraft and life support and other subsystems?

1.1.3.3.1.1.1 HIGH VACUUM INSULATION

What are the aspects of thermal control of spacecraft by the use of high vacuum insulation and what are the conceptual configurations considered?

(CRITICAL ISSUES IN TABLE 1)

1.1.3.3.1.1.2
ABLATIVE INSULATION

What are the aspects of thermal control of space cabins by the use of ablative insulation and what are the conceptual configurations considered?

(CRITICAL ISSUES IN TABLE 1)

1.1.3.3.1.1.3
CONDUCTION INSULATION

What are the aspects of passive thermal control of space cabins by the use of conduction insulation and what are the conceptual configurations considered?

(CRITICAL ISSUES IN TABLE 1)

(SEE CHART 1-24)

1.1.3.3.1.2 RADIATIVE SURFACES

What are the processes involved in passive thermal control of space cabins by the use of radiative surfaces and what are their potential uses and effects on the crew, spacecraft and life support and other subsystems?

1.1.3.3.1.2.1
FIXED SURFACES

What are the aspects of passive thermal control by fixed radiative surfaces and what are the conceptual configurations considered?

(CRITICAL ISSUES IN TABLE 1)

1.1.3.3.1.2.2
VARIABLE SURFACES

What are the aspects of passive thermal control by variable radiative surfaces and what are the conceptual configurations considered?

(CRITICAL ISSUES IN TABLE 1)

Chart 1-36. Manned Spaceflight Capability –
Heating Systems

(SEE CHART 1-24)

1.1.3.3.2.1
HEATING SYSTEMS

What are the basic approaches used in heating of spacecraft and should they be investigated under space flight conditions?

1.1.3.3.2.1.1 HEAT STORAGE SYSTEMS

What are the processes involved in heat storage in spacecraft and what are their potential uses and effects on the crew, spacecraft and life support and other subsystems?

1.1.3.3.2.1.2 FLUID TRANSPORT SYSTEMS

What are the methods involved in testing fluid transport systems and what are their potential uses and effects on the crew, spacecraft and life support and other subsystems?

(CRITICAL ISSUES IN TABLE 1)

1.1.3.3.2.1.1.1
PHASE CHANGE

What are the aspects of heat storage utilizing phase change processes and what are the conceptual configurations considered?

(CRITICAL ISSUES IN TABLE 1)

1.1.3.3.2.1.1.2
SINGLE PHASE

What are the aspects of heat storage utilizing single phase processes and what are the conceptual configuration considered?

(CRITICAL ISSUES IN TABLE 1)

Chart 1-37. Manned Spaceflight Capability – Cooling Systems

(SEE CHART 1-24)

1.1.3.3.2.2 COOLING SYSTEMS

What are the basic approaches used in cooling of spacecraft and should they be investigated under space flight conditions?

1.1.3.3.2.2.1 HEAT SINK

What are the processes involved in heat sinks in thermal control systems and what are their potential uses and effects on the crew, spacecraft and life support and other subsystems?

1.1.3.3.2.2.1.1 EVAPORATIVE

What are the aspects of heat sink utilization by evaporative coolers and what are the conceptual configurations considered?

(NO CRITICAL ISSUES DERIVED)

1.1.3.3.2.2.1.2 RADIATIVE COOLING

What are the aspects of heat rejection by active space radiators and what are the conceptual configurations considered?

1.1.3.3.2.2.1.2.1 CONDENSING

What are the aspects of heat rejection by the use of condensing radiators and what are the conceptual configurations considered?

(CRITICAL ISSUES IN TABLE 1)

1.1.3.3.2.2.1.2.2 SINGLE PHASE

What are the aspects of heat rejection by single phase type space radiators and what are the conceptual configurations considered?

(NO CRITICAL ISSUES DERIVED)

1.1.3.3.2.2.2 FLUID TRANSPORT SYSTEMS

What are the cooling processes involved in fluid transport systems in spacecraft and what are their potential uses and effects on the crew, spacecraft and life support and other subsystems?

1.1.3.3.2.2.2.1 NON-CONDENSING HEAT EXCHANGERS

What are the aspects of fluid transport systems utilizing cabin heat exchange equipment and what are the conceptual configurations considered?

(NO CRITICAL ISSUES DERIVED)

1.1.3.3.2.2.2.2 CONDENSERS

What are the aspects of humidity and heat rejection by the use of condensers and what are the conceptual configurations considered?

(CRITICAL ISSUES IN TABLE 1)

Chart 1-38. Manned Spaceflight Capability - Water Storage/Preservation

(SEE CHART 1-25)

1.1.3.4.1 STORAGE/ PRESERVATION

What are the processes involved in storage/ preservation water management and what are their potential uses and effects on the crew, the spacecraft, and the life support and other vehicle systems.

What are the various methods used in storage/preservation of water in spacecrafts?

1.1.3.4.1.1 BLADDER TANK STORAGE

Has feasibility been established for all components and processes involved in bladder tank storage processes?

(CRITICAL ISSUES IN TABLE 1)

1.1.3.4.1.2 CHEMICAL PRESERVATION

Has feasibility been established for all components and processes involved in chemical preservation water management?

(CRITICAL ISSUES IN TABLE 1)

1.1.3.4.1.3 PASTEURIZATION

How is the pasteurization process applied to the storage and preservation of water in spacecraft systems and what are its potential uses and effects on the crew, the spacecraft, and the life support and other subsystems?

(CRITICAL ISSUES IN TABLE 1)

(SEE CHART 1-25)

1.1.3.4.2.2 PHASE CHANGE

Has feasibility been established for all components and processes involved in water reclamation by phase change?

What are the various methods of water reclamation utilizing a phase change considered for spacecraft?

1.1.3.4.2.2.1 AIR EVAPORATION

What are the aspects of water reclamation by air evaporation process and what are the conceptual configurations considered?

(CRITICAL ISSUES IN TABLE 1)

1.1.3.4.2.2.2 VAPOR DIFFUSION

What are the aspects of water reclamation by membrane diffusion and what are the conceptual configurations considered?

(CRITICAL ISSUES IN TABLE 1)

1.1.3.4.2.2.3 VAPOR DIFFUSION COMPRESSION

What are the aspects of water reclamation by vapor diffusion and what are the conceptual configurations considered?

(CRITICAL ISSUES IN TABLE 1)

1.1.3.4.2.2.4 VAPOR PYROLYSIS/CATALYSIS

What are the aspects of water reclamation by vapor pyrolysis/catalysis and what are the conceptual configurations considered?

(CRITICAL ISSUES IN TABLE 1)

1.1.3.4.2.2.5 VAPOR COMPRESSION

What are the aspects of water reclamation by vapor compression and what are the conceptual configurations considered?

(CRITICAL ISSUES IN TABLE 1)

Chart 1-40. Manned Spaceflight Capability – Recovery

(SEE CHART 1-26)

1.1.3.5.4 RECOVERY

What are the waste management reclamation processes considered and what are their potential uses and effects on the crew, spacecraft and life support and other subsystems?

- **1.1.3.5.4.1 URINE**

  Reference Water Recovery.

  (NO CRITICAL ISSUES DERIVED)

- **1.1.3.5.4.2 FECES/REFUSE**

  What are the aspects of reclamation of feces and/or refuse by incineration/condensation, with oxidation and/or biological methods, and what are the conceptual configurations considered?

  - **1.1.3.5.4.2.1 RESIDUE**

    Reference Food Management.

    (NO CRITICAL ISSUES DERIVED)

  - **1.1.3.5.4.2.2 WATER**

    Reference Water Management.

    (NO CRITICAL ISSUES DERIVED)

Chart 1-41. Manned Spaceflight Capability – Atmosphere Contaminants Control

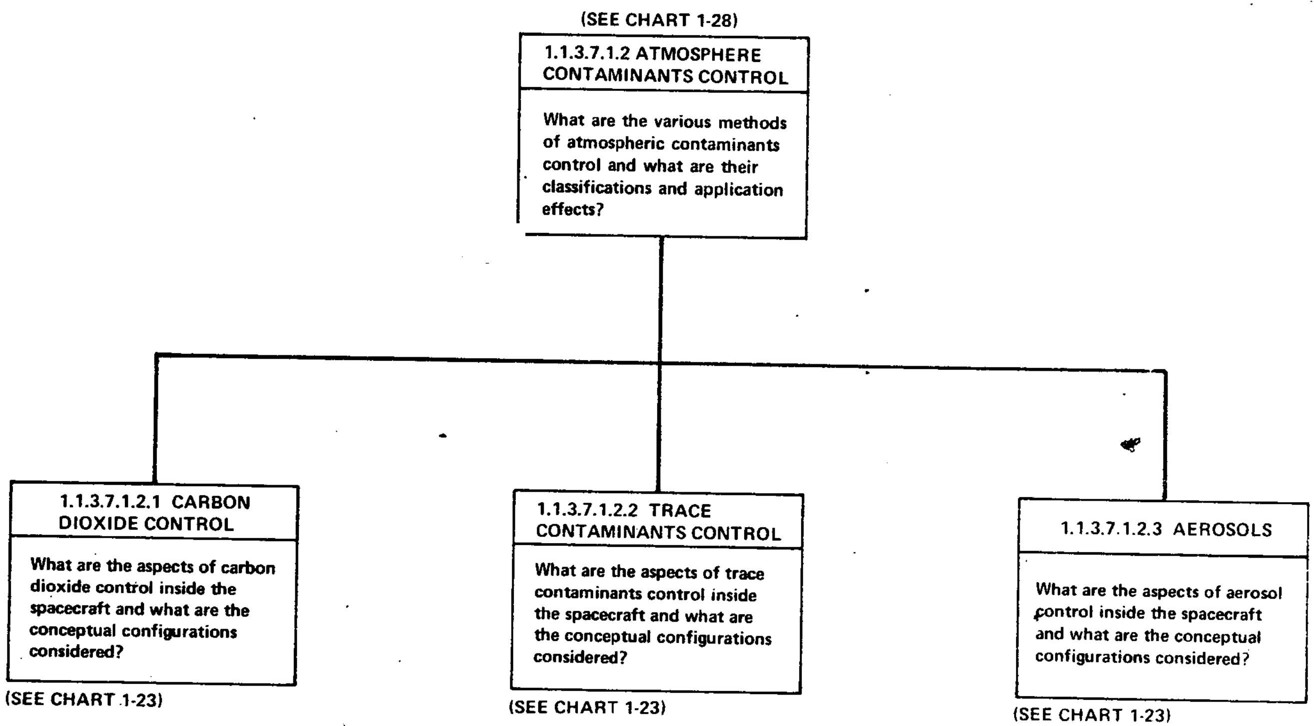


Chart 1-42. Manned Spaceflight Capability – Data Management Subsystems

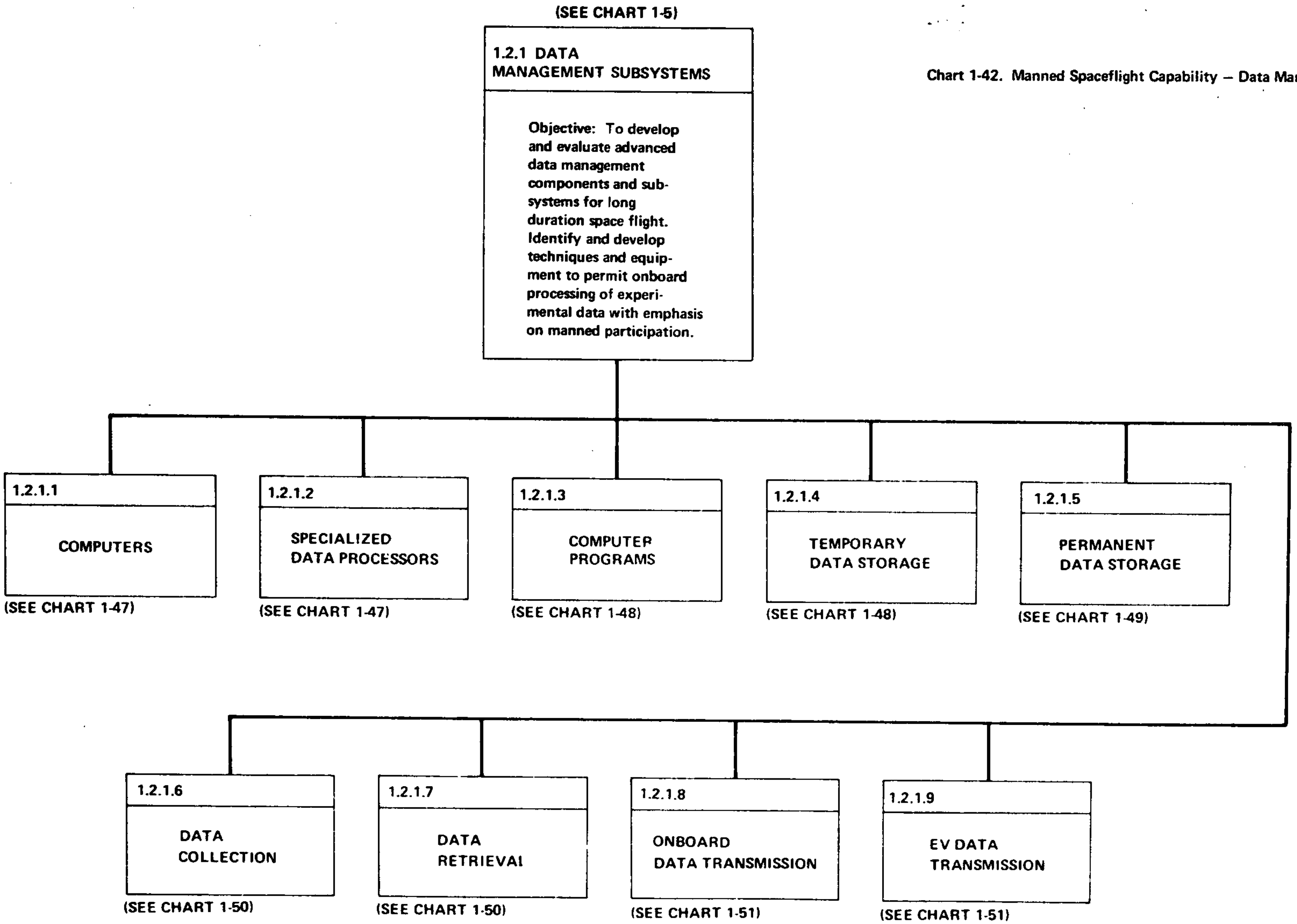


Chart 1-43. Manned Spaceflight Capability – Electrical Power

(SEE CHART 1-5)

1.2.2 ELECTRICAL POWER

Objective: Develop and evaluate components and subsystems for providing electrical power to advanced space vehicles. Evaluate man's capability in operating, controlling, and maintaining such systems.

- 1.2.2.1 SOLAR CELLS (SEE CHART 1-52)
- 1.2.2.2 BATTERY (SEE CHART 1-52)
- 1.2.2.3 FUEL CELLS (CRITICAL ISSUES IN TABLE 1)
- 1.2.2.4 BRAYTON CYCLE (SEE CHART 1-53)
- 1.2.2.5 RANKINE CYCLE (SEE CHART 1-53)
- 1.2.2.6 THERMOELECTRIC (CRITICAL ISSUES IN TABLE 1)
- 1.2.2.7 THERMIONICS (CRITICAL ISSUES IN TABLE 1)
- 1.2.2.8 NUCLEAR HEAT SOURCES (Reactors and Isotopes) (CRITICAL ISSUES IN TABLE 1)
- 1.2.2.9 RADIATORS (SEE CHART 1-53)
- 1.2.2.10 POWER CONDITIONING (CRITICAL ISSUES IN TABLE 1)
- 1.2.2.11 POWER DISTRIBUTION (CRITICAL ISSUES IN TABLE 1)

1.2.3 STABILIZATION AND CONTROL

Objective: Develop and evaluate technology, hardware, and procedures for the stabilization and control of advanced space vehicles, both rotating (artificial gravity) and nonrotating, with special emphasis on (1) coarse and fine attitude control, (2) rate stabilization, (3) station keeping, and (4) fine pointing (Example: large optical telescope to within 0.01 arc sec).

(SEE CHART 1-5)

1.2.3.1

FORCE/MOMENT PERTURBATION

(SEE CHART 1-54)

1.2.3.2

SENSORS

(SEE CHART 1-55)

1.2.3.3

CONTROL FORCE/ MOMENT GENERATORS

(SEE CHART 1-56)

1.2.3.4

CONTROL SYSTEM DESIGN

(SEE CHART 1-57)

Chart 1-45. Manned Spaceflight Capability — Navigation and Guidance

(SEE CHART 1-5)

1.2.4 NAVIGATION AND GUIDANCE

Objective: To develop and evaluate technology and equipment for spacecraft components and subsystems with which man interacts or which are required to provide man space flight capabilities.

- 1.2.4.1 ATTITUDE AND POSITION SENSORS (SEE CHART 1-67)
- 1.2.4.2 RENDEZVOUS AND DOCKING SENSORS
  - 1.2.4.2.1 LASER OPTICAL RADAR (CRITICAL ISSUES IN TABLE 1)
  - 1.2.4.2.2 MICROWAVE RADAR (NO CRITICAL ISSUES DERIVED)
- 1.2.4.3 SOFTWARE (SEE CHART 1-68)
- 1.2.4.4 SPACE LOGISTICS SUPPORT (SEE CHART 1-69)
- 1.2.4.5 ONBOARD DATA PROCESSING (SEE CHART 1-69)

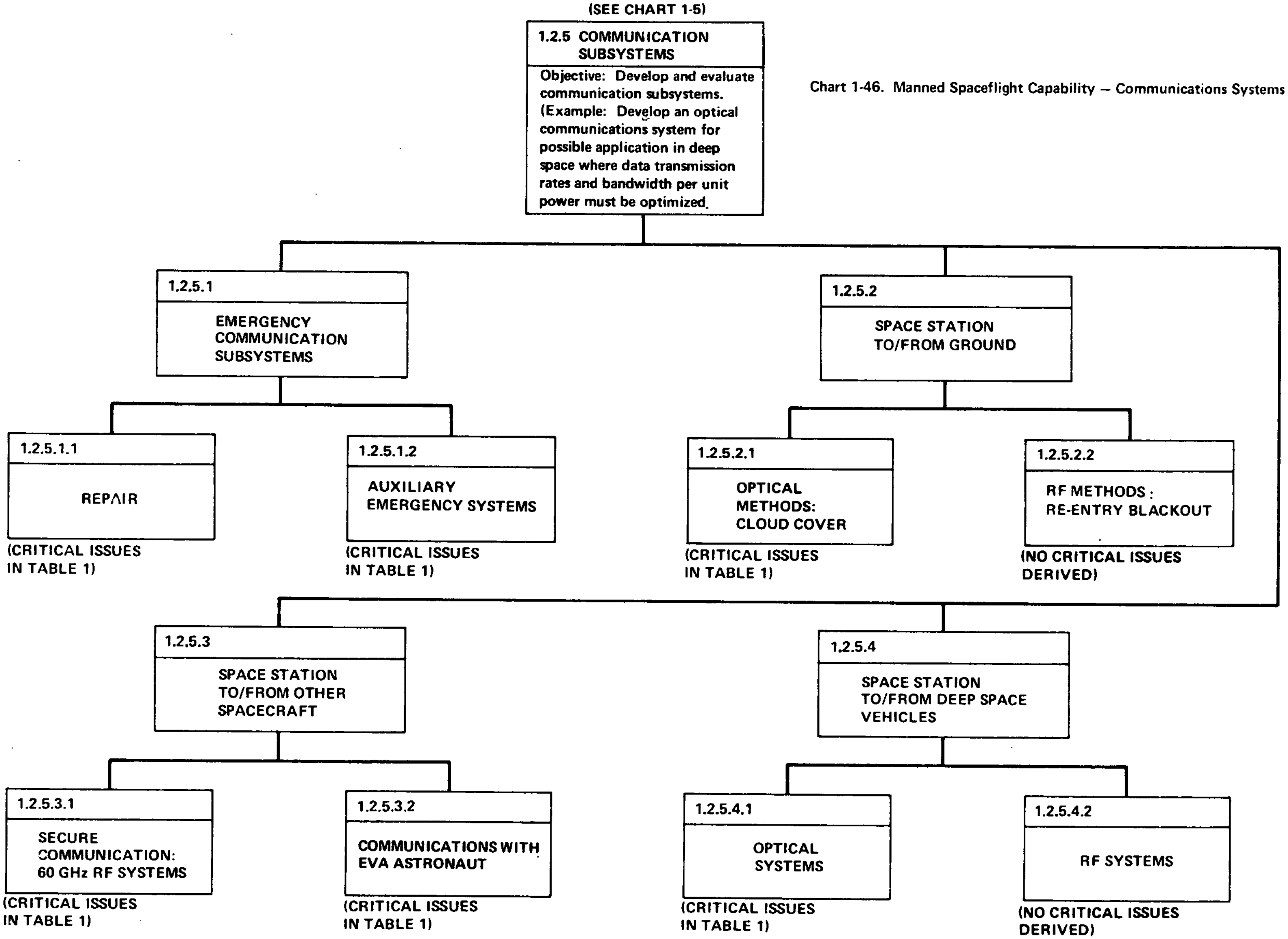


Chart 1-46. Manned Spaceflight Capability – Communications Systems

Chart 1-47. Manned Spaceflight Capability – Computers / Data Processors

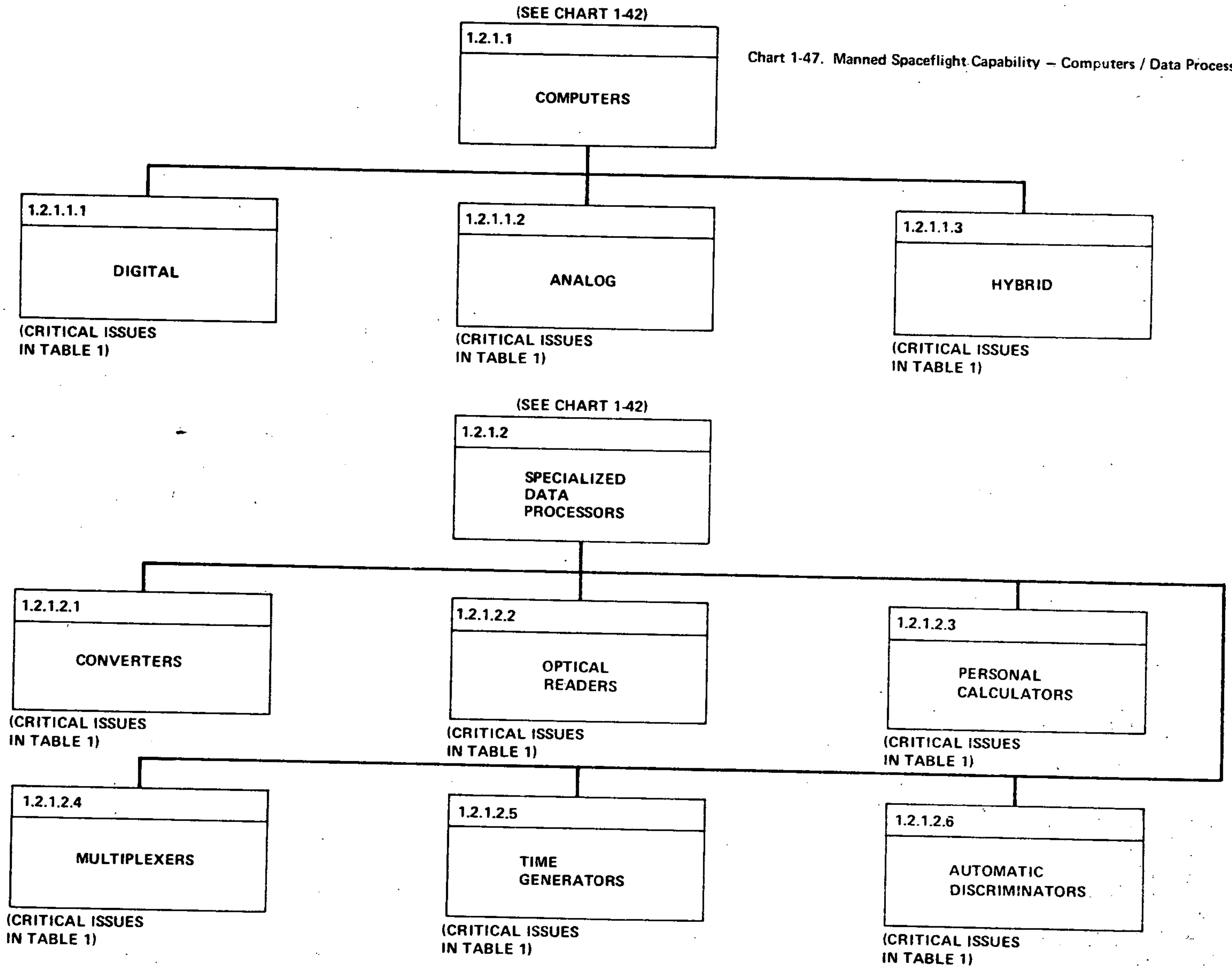
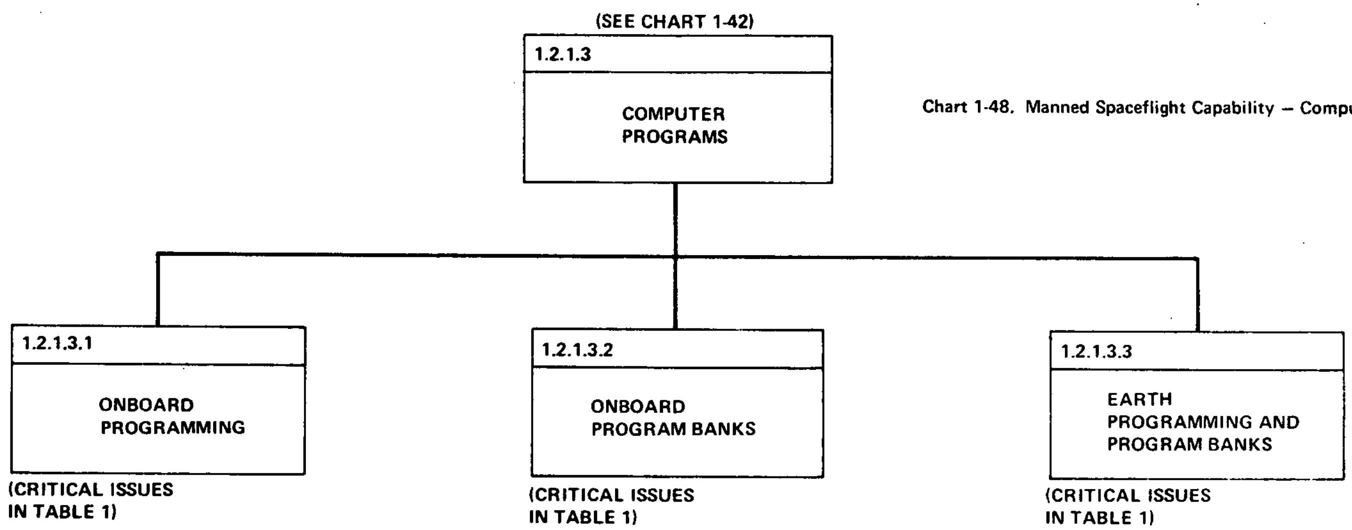


Chart 1-48. Manned Spaceflight Capability – Computer Programs / Data Storage



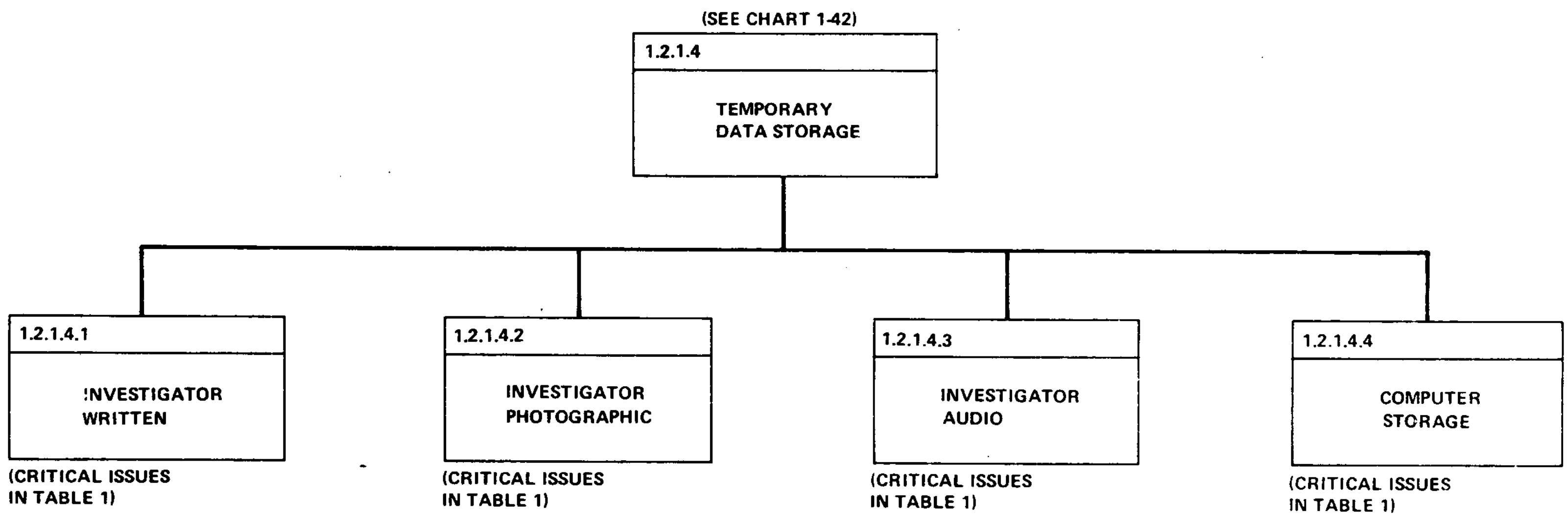
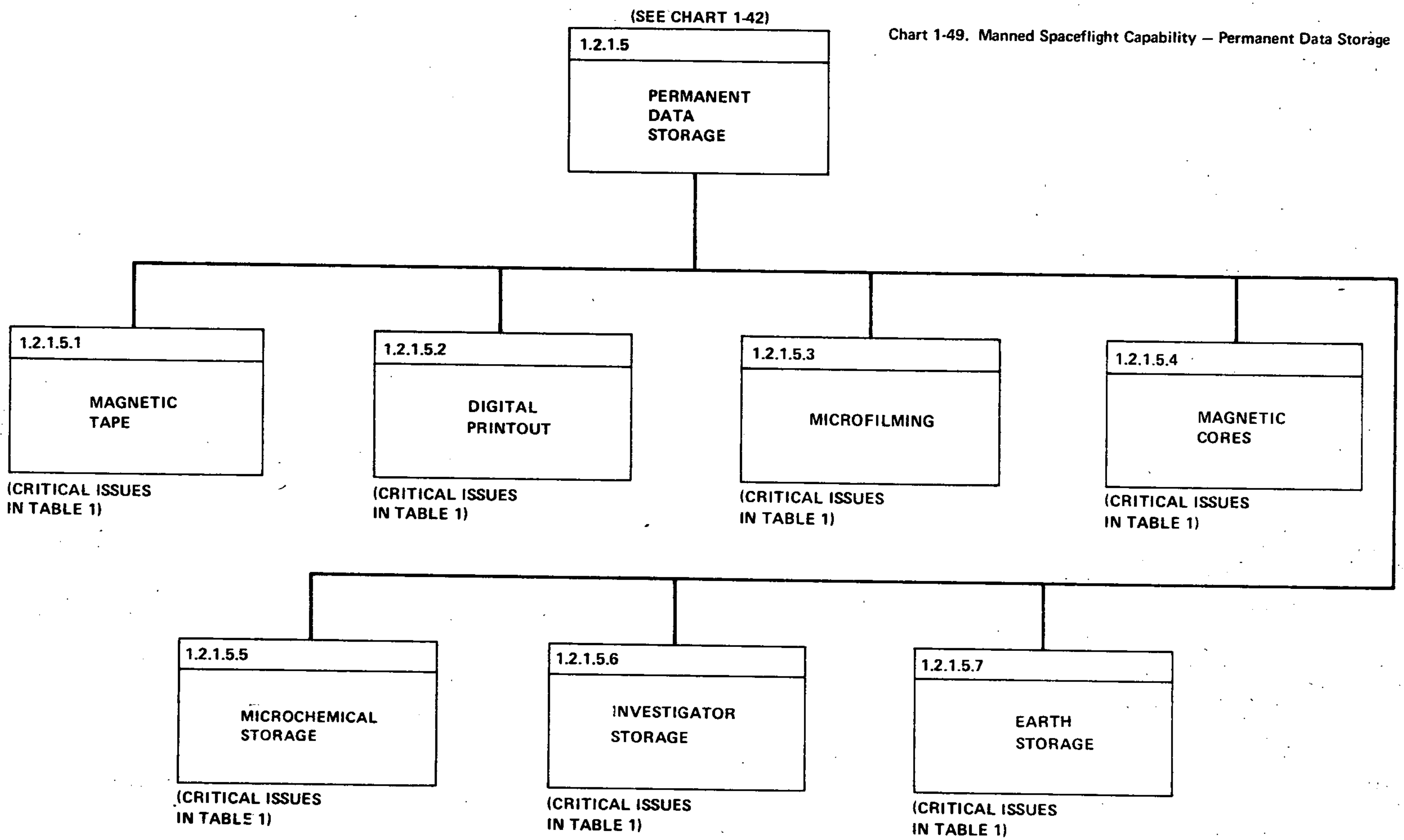


Chart 1-49. Manned Spaceflight Capability – Permanent Data Storage



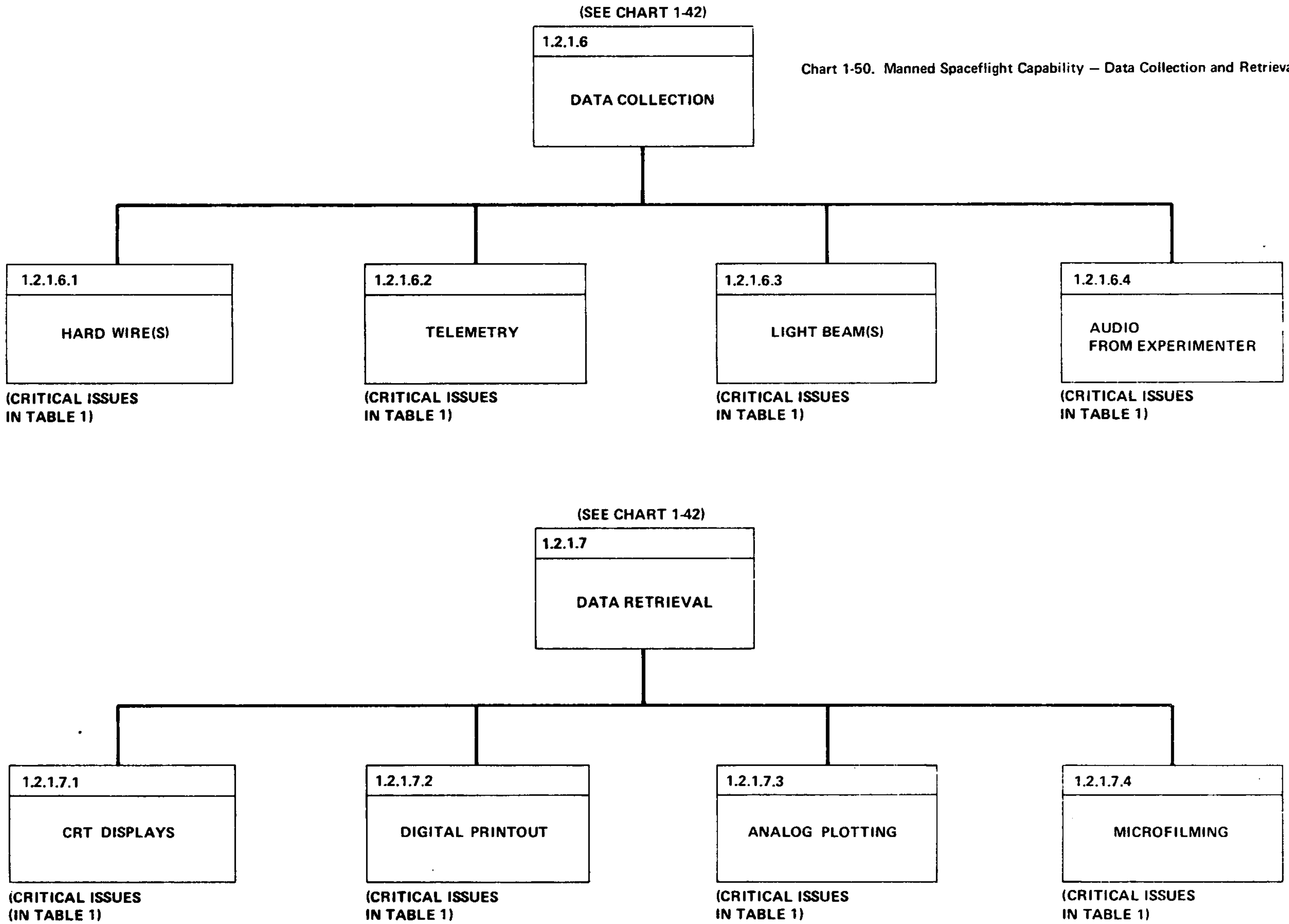


Chart 1-50. Manned Spaceflight Capability – Data Collection and Retrieval

Chart 1-51. Manned Spaceflight Capability – Data Transmission

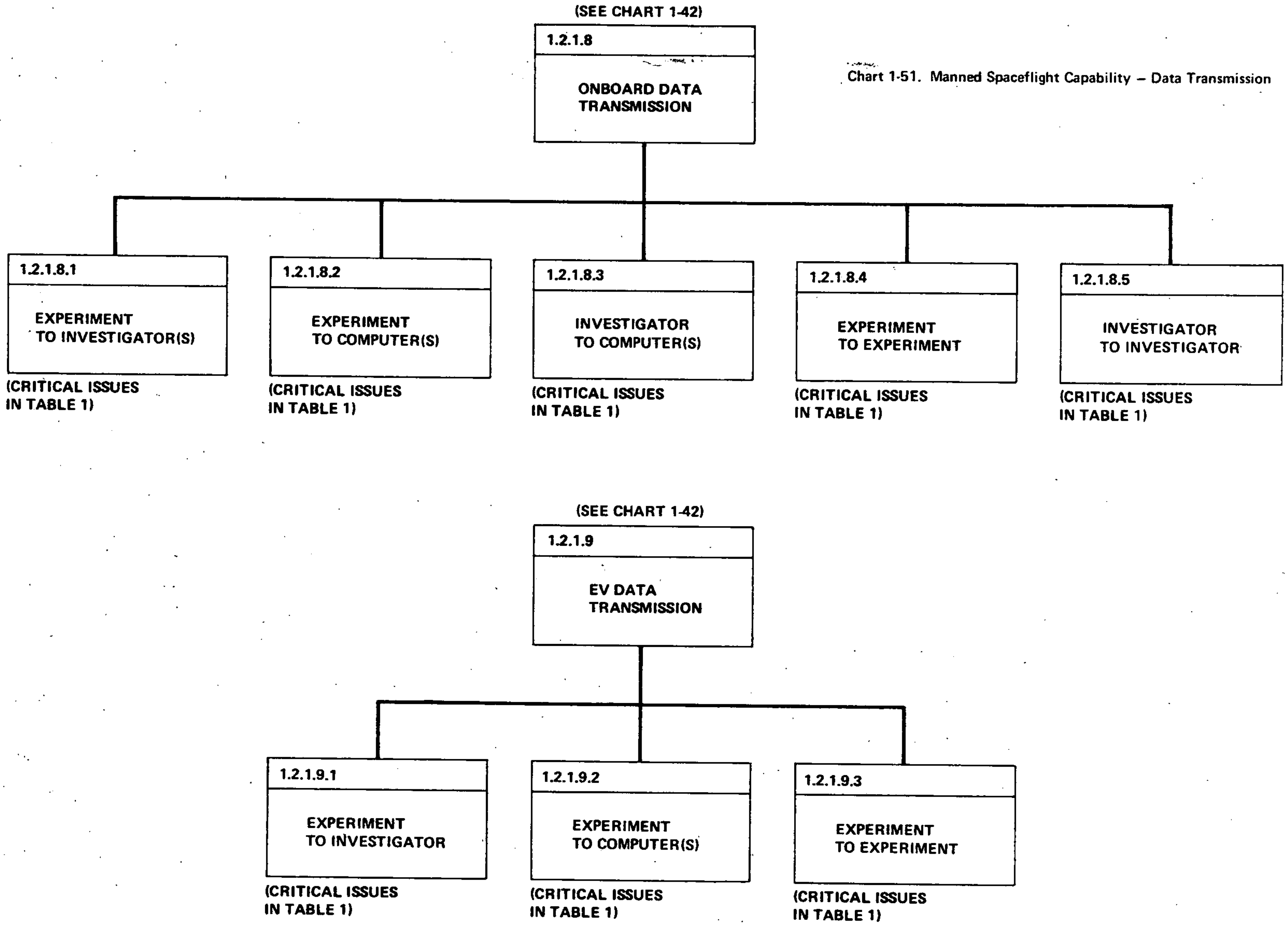
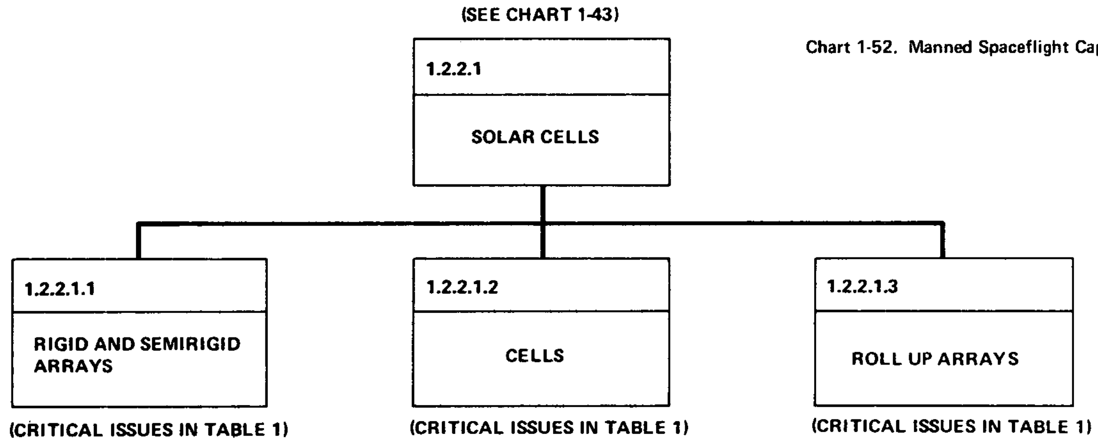


Chart 1-52. Manned Spaceflight Capability – Solar Cells / Battery



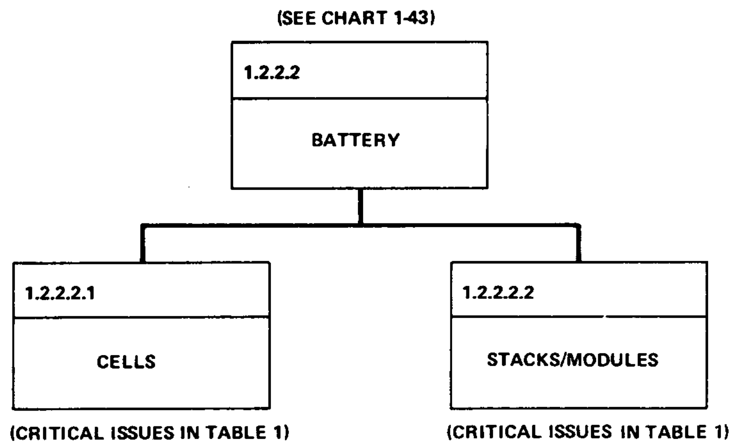


Chart 1-53. Manned Spaceflight Capability – Brayton Cycles, Rankine Cycles and Radiators

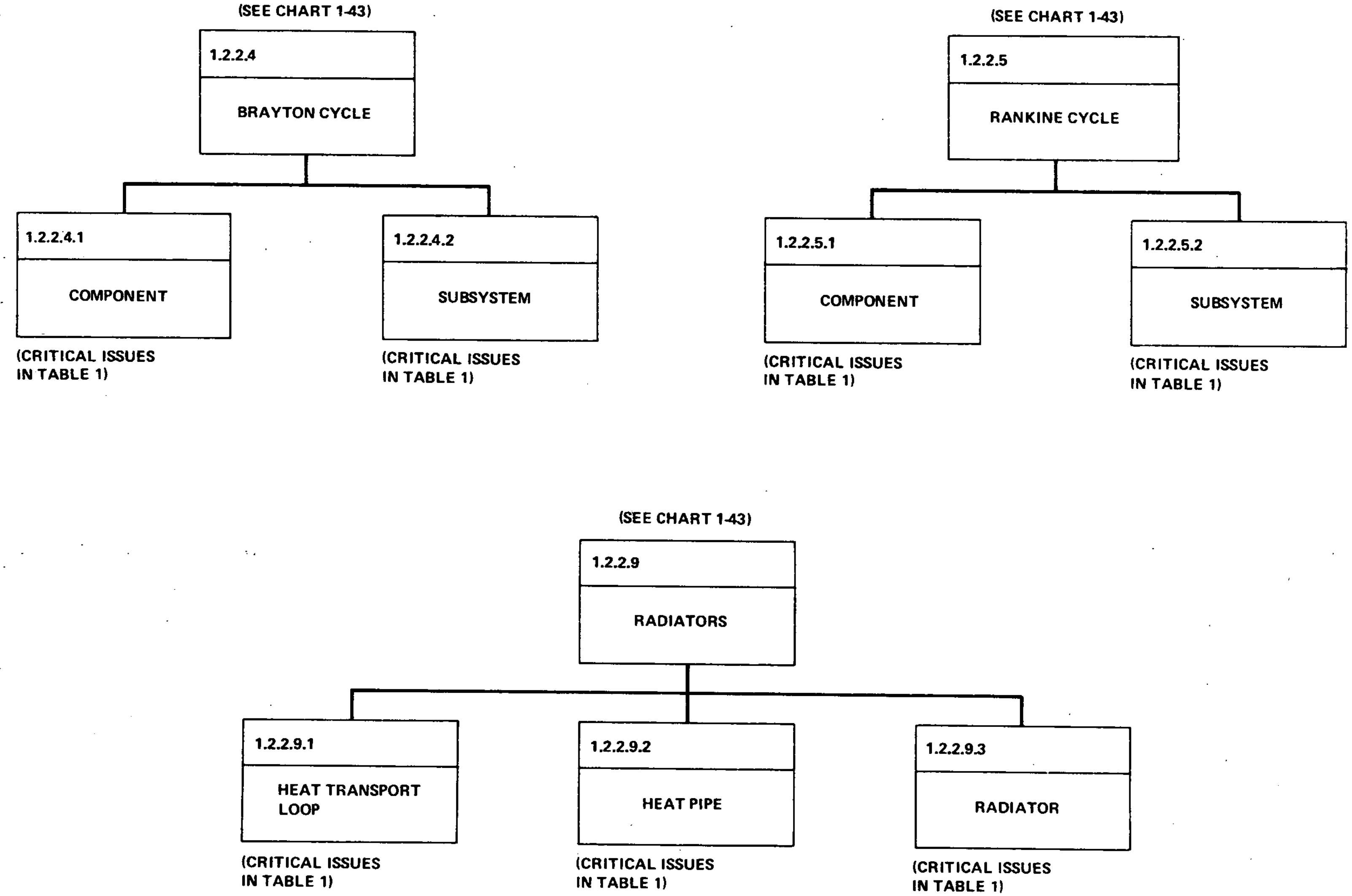


Chart 1-54. Manned Spaceflight Capability – Force / Moment Perturbation

(SEE CHART 1-44)

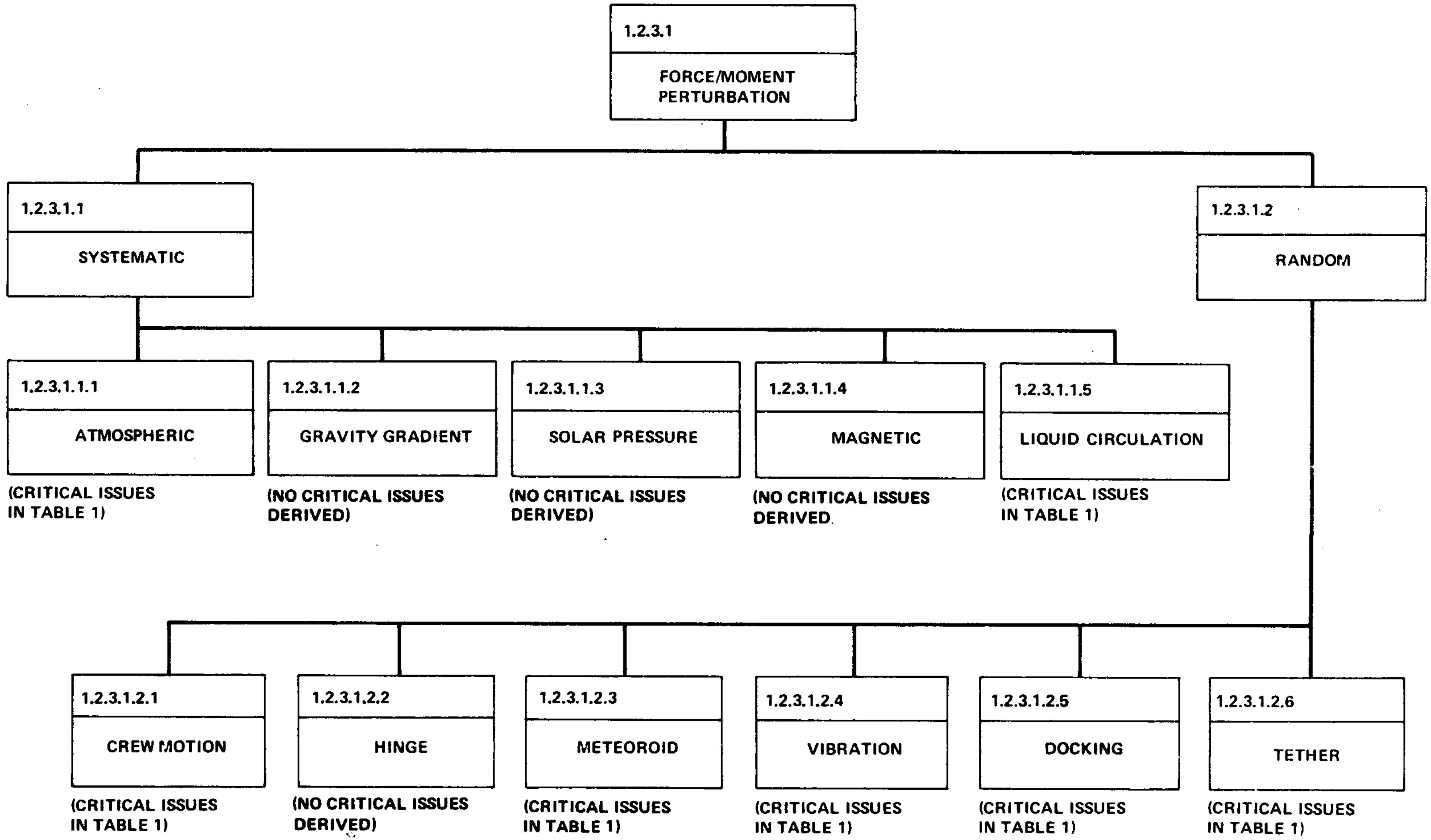


Chart 1-55. Manned Spaceflight Capability – Sensors

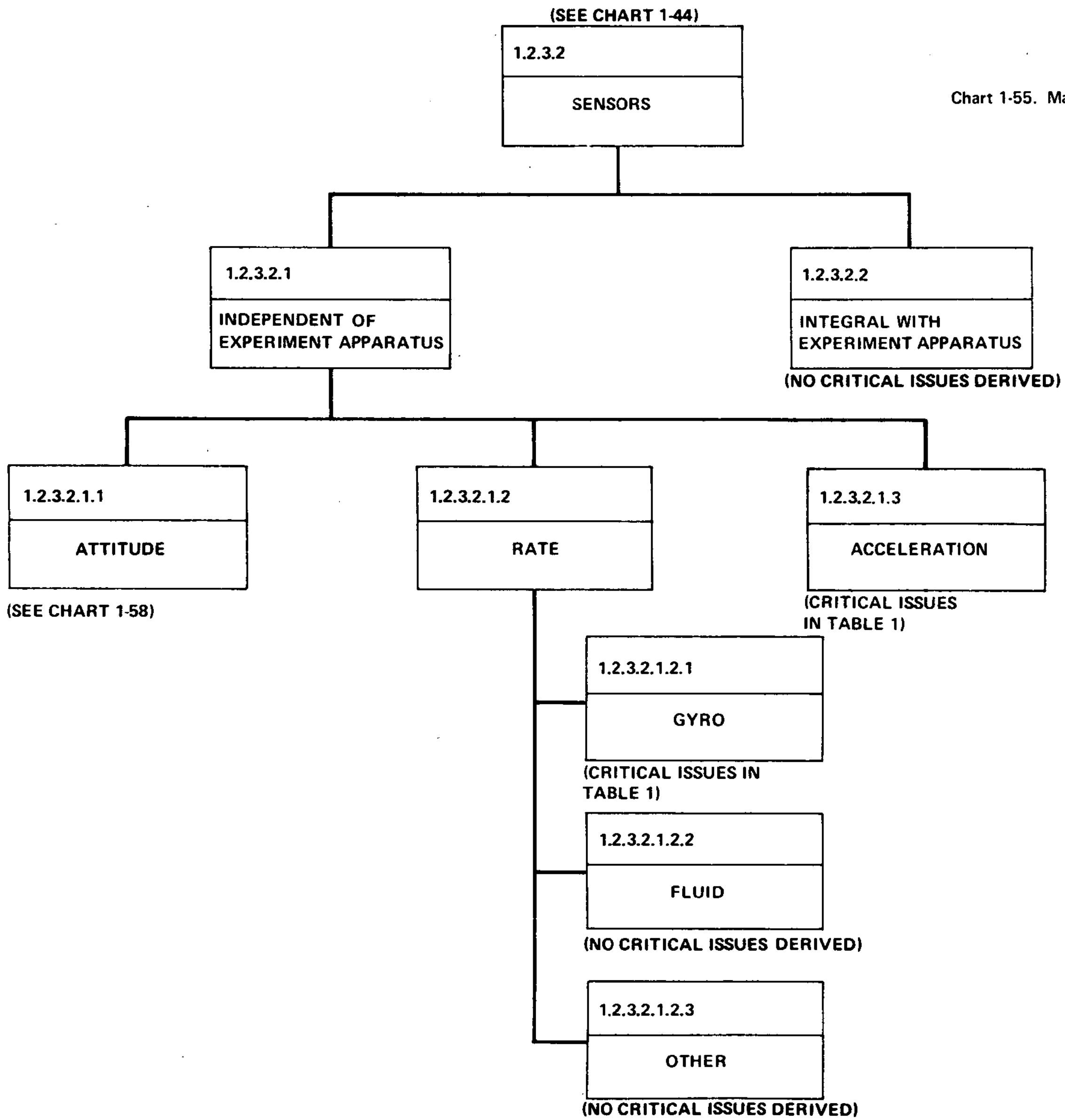


Chart 1-56. Manned Spaceflight Capability – Control Force / Moment Generators

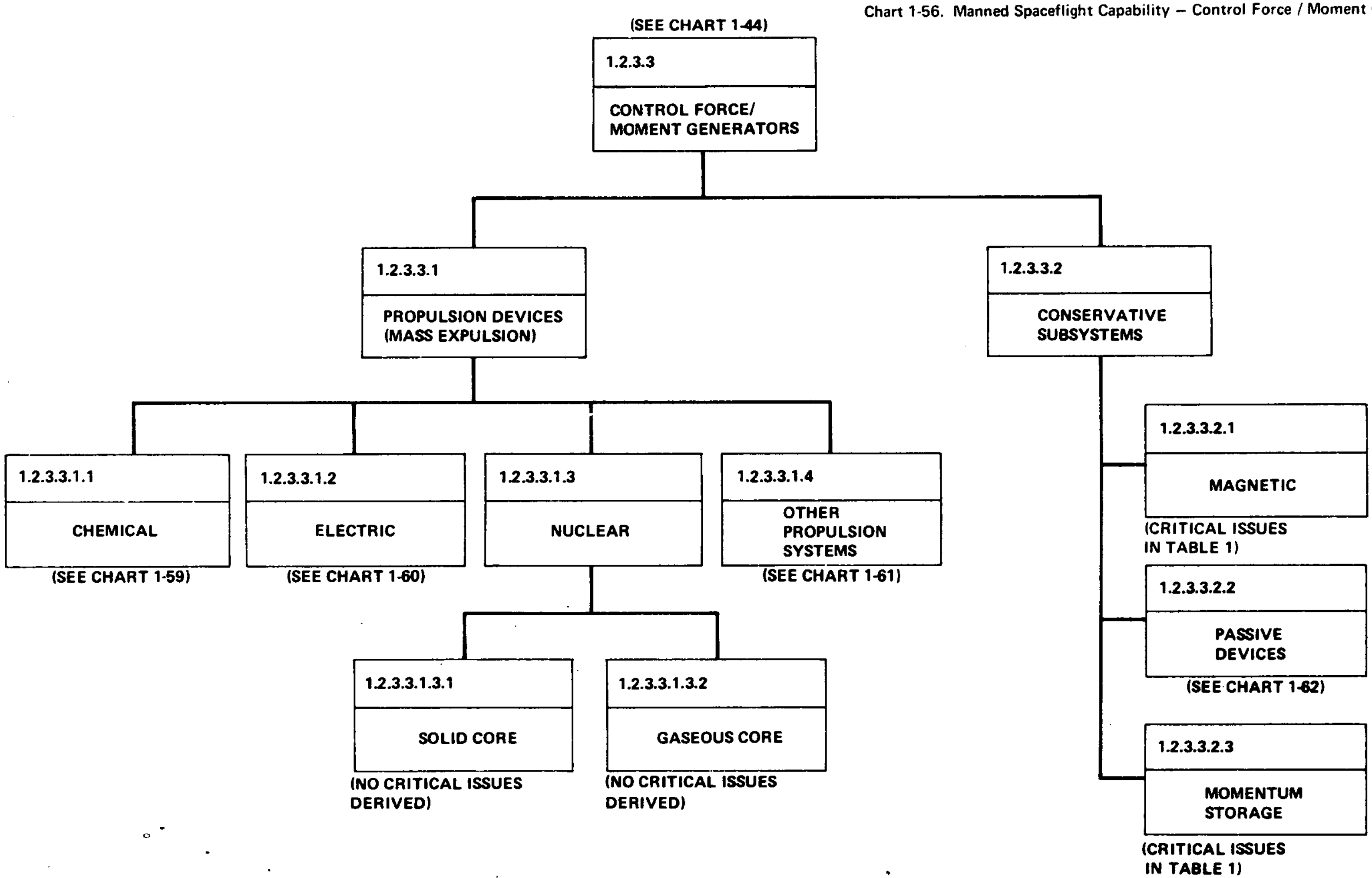


Chart 1-57. Manned Spaceflight Capability – Control System Design

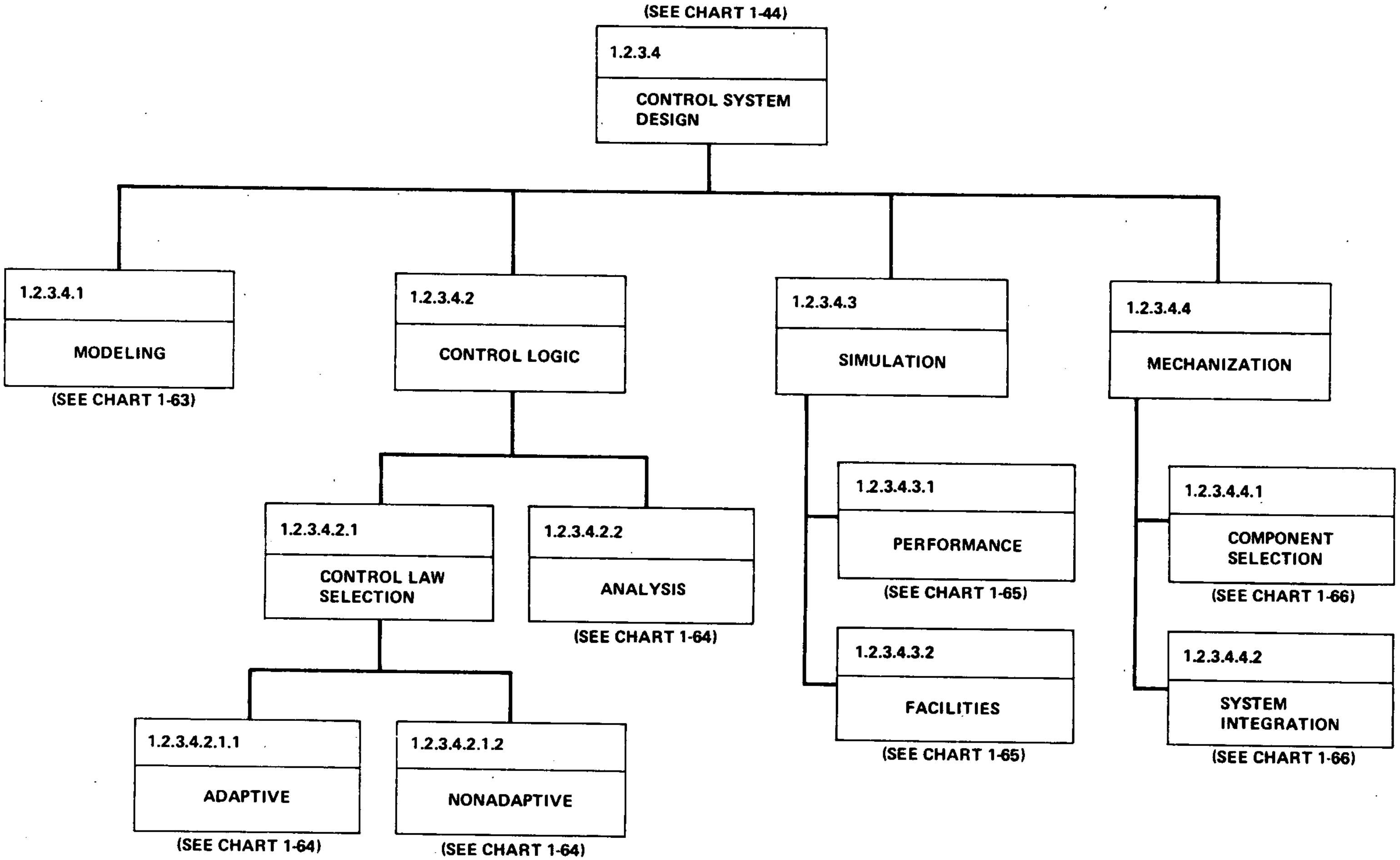


Chart 1-58. Manned Spaceflight Capability – Attitude

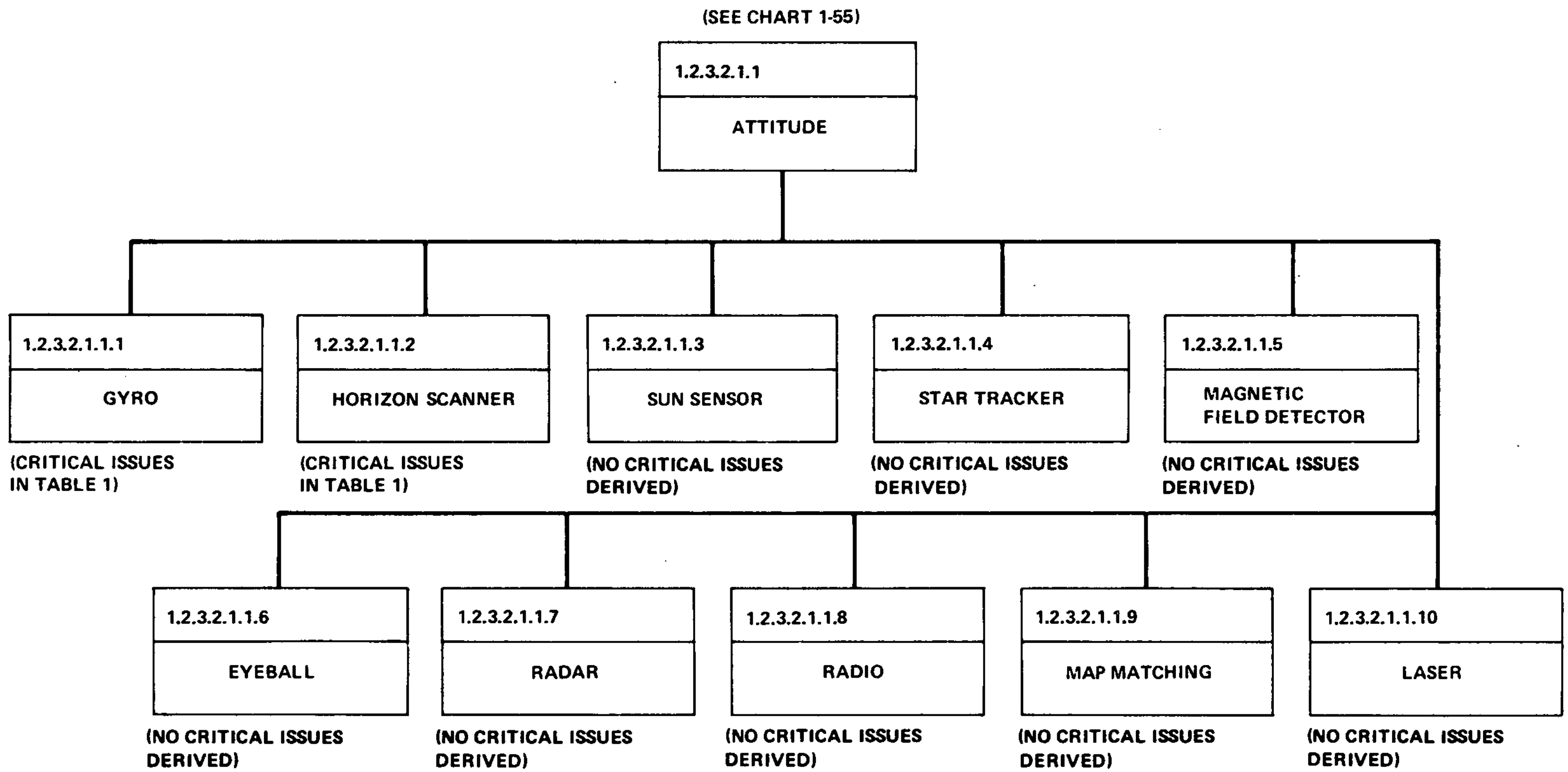


Chart 1-59. Manned Spaceflight Capability – Chemical

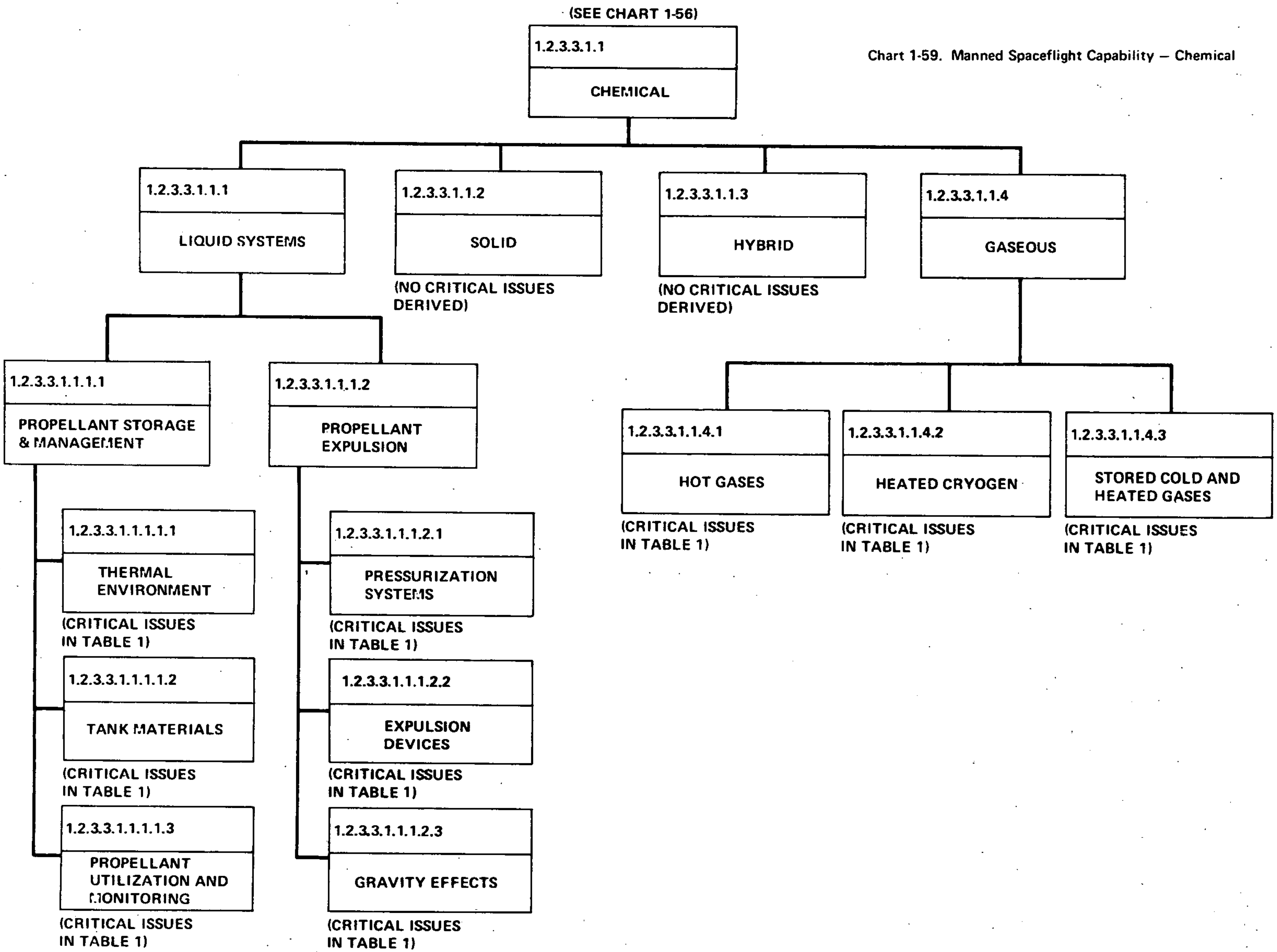


Chart 1-60. Manned Spaceflight Capability – Electric

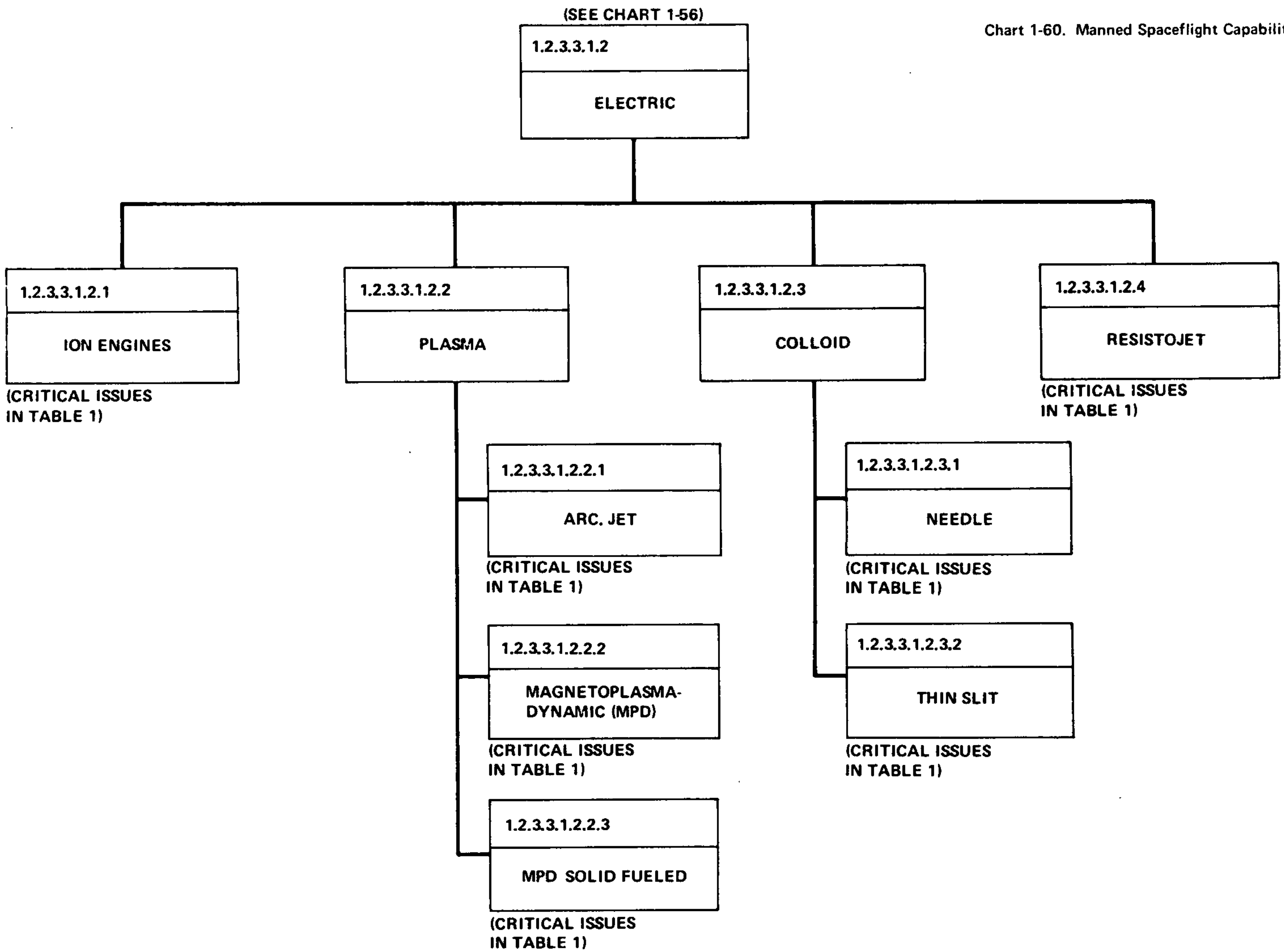


Chart 1-61. Manned Spaceflight Capability – Other Propulsion Systems

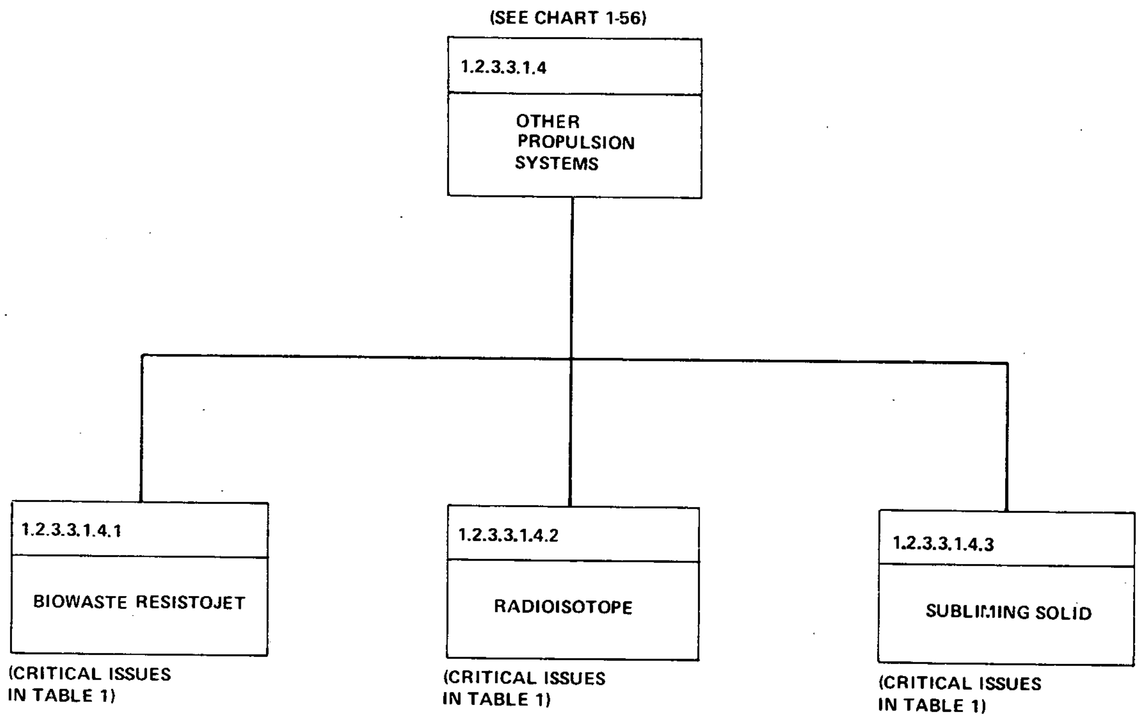


Chart 1-62. Manned Spaceflight Capability – Passive Devices / Momentum Storage

(SEE CHART 1-56)

1.2.3.3.2.2 PASSIVE DEVICES

- 1.2.3.3.2.2.1 FLUID (NO CRITICAL ISSUES DERIVED)
- 1.2.3.3.2.2.2 SPRING MASS (NO CRITICAL ISSUES DERIVED)
- 1.2.3.3.2.2.3 MASS EXTENSION (NO CRITICAL ISSUES DERIVED)
- 1.2.3.3.2.2.4 GRAVITY GRADIENT (NO CRITICAL ISSUES DERIVED)
- 1.2.3.3.2.2.5 SOLAR PRESSURE (NO CRITICAL ISSUES DERIVED)

Chart 1-63. Manned Spaceflight Capability – Modeling

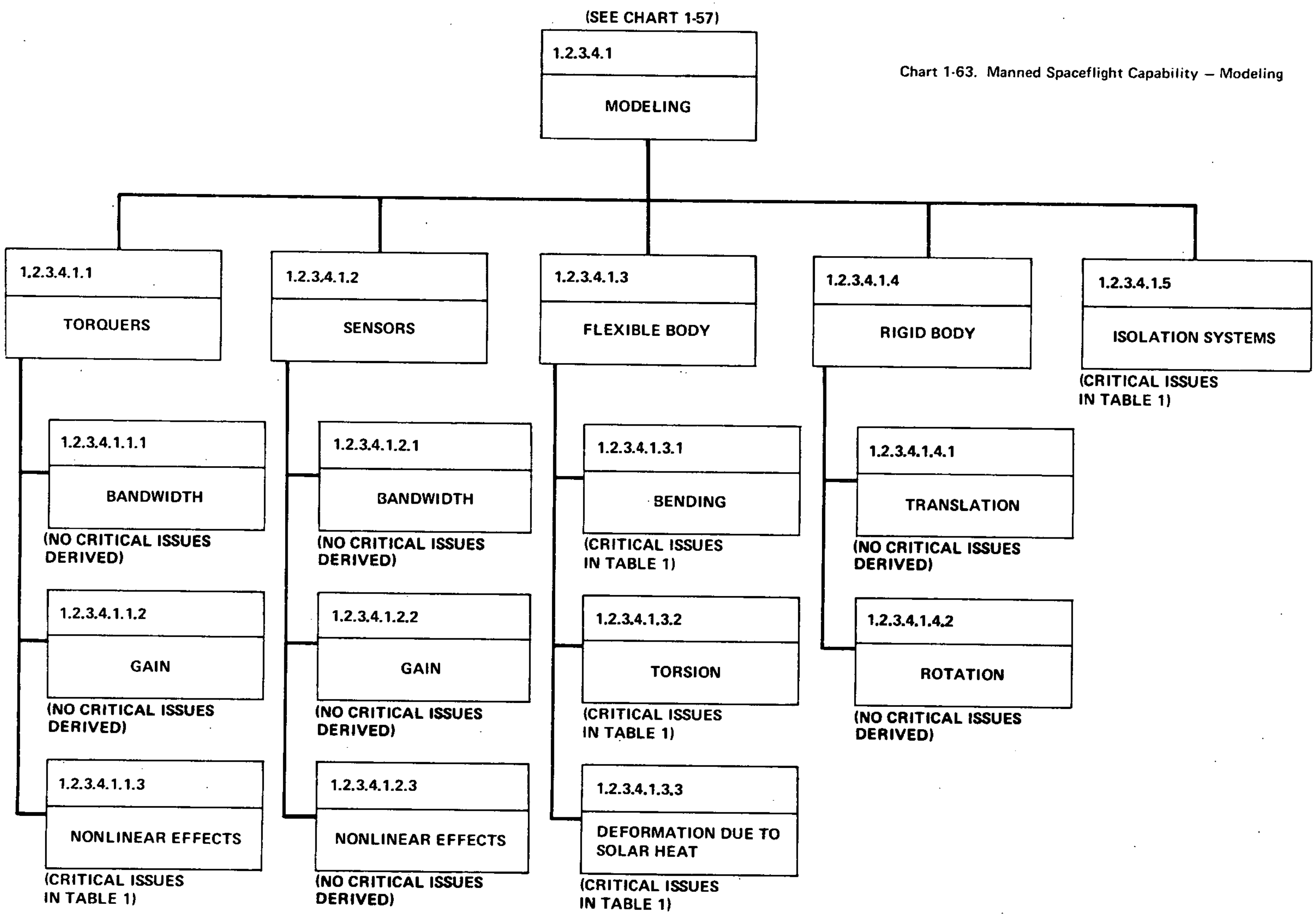


Chart 1-64. Manned Spaceflight Capability – Control Logic

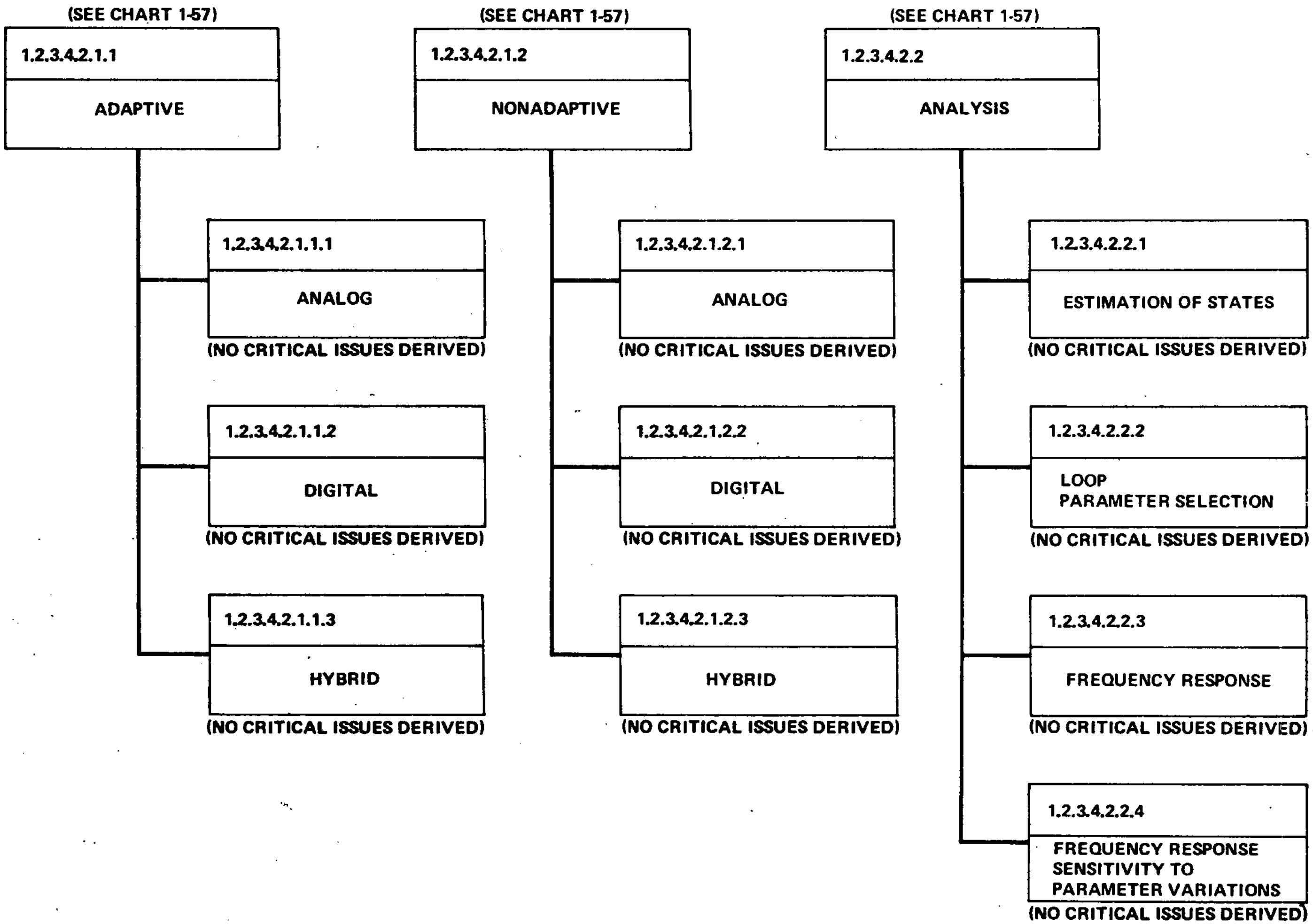


Chart 1-65. Manned Spaceflight Capability – Simulation

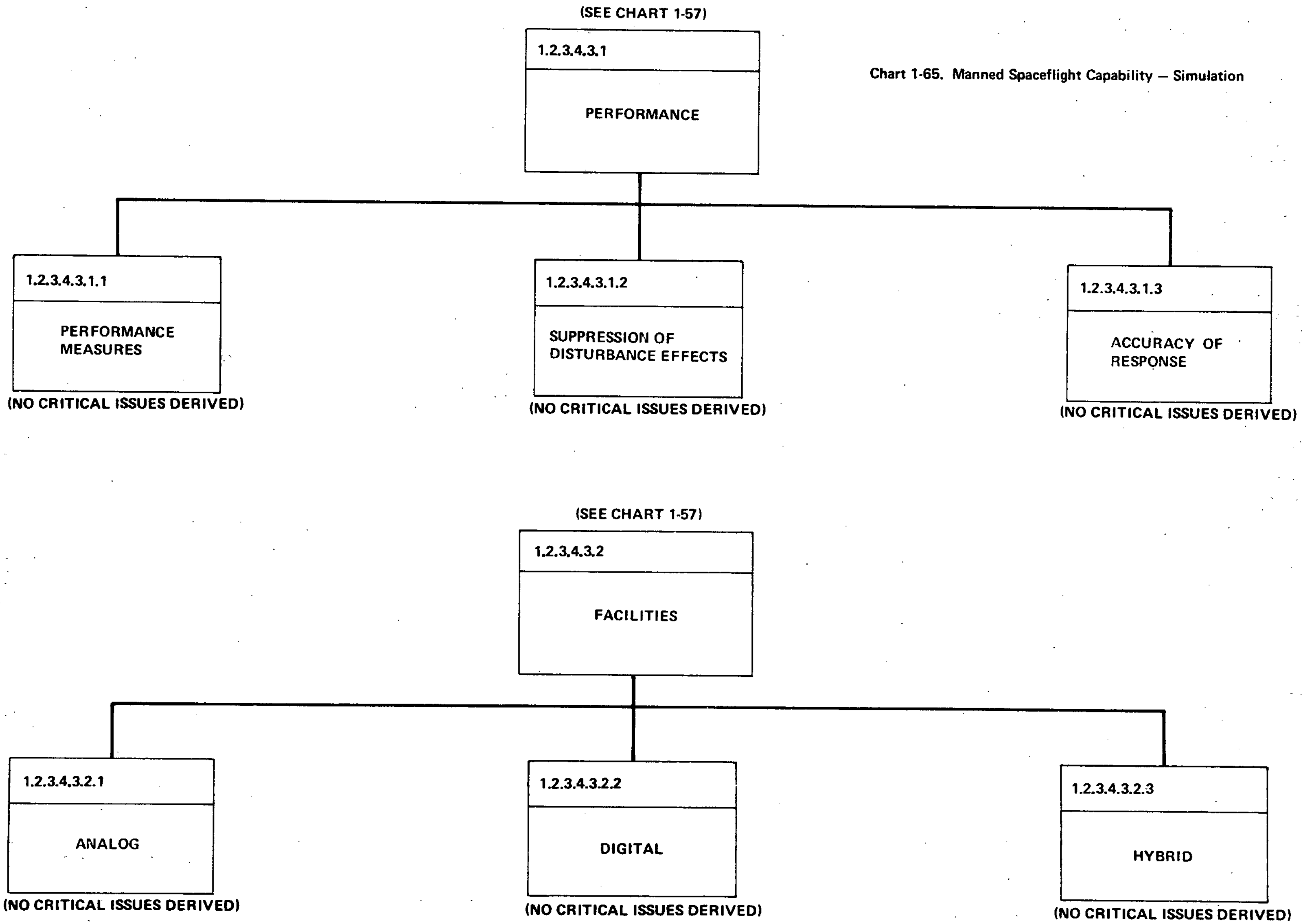


Chart 1-66. Manned Spaceflight Capability – Mechanization

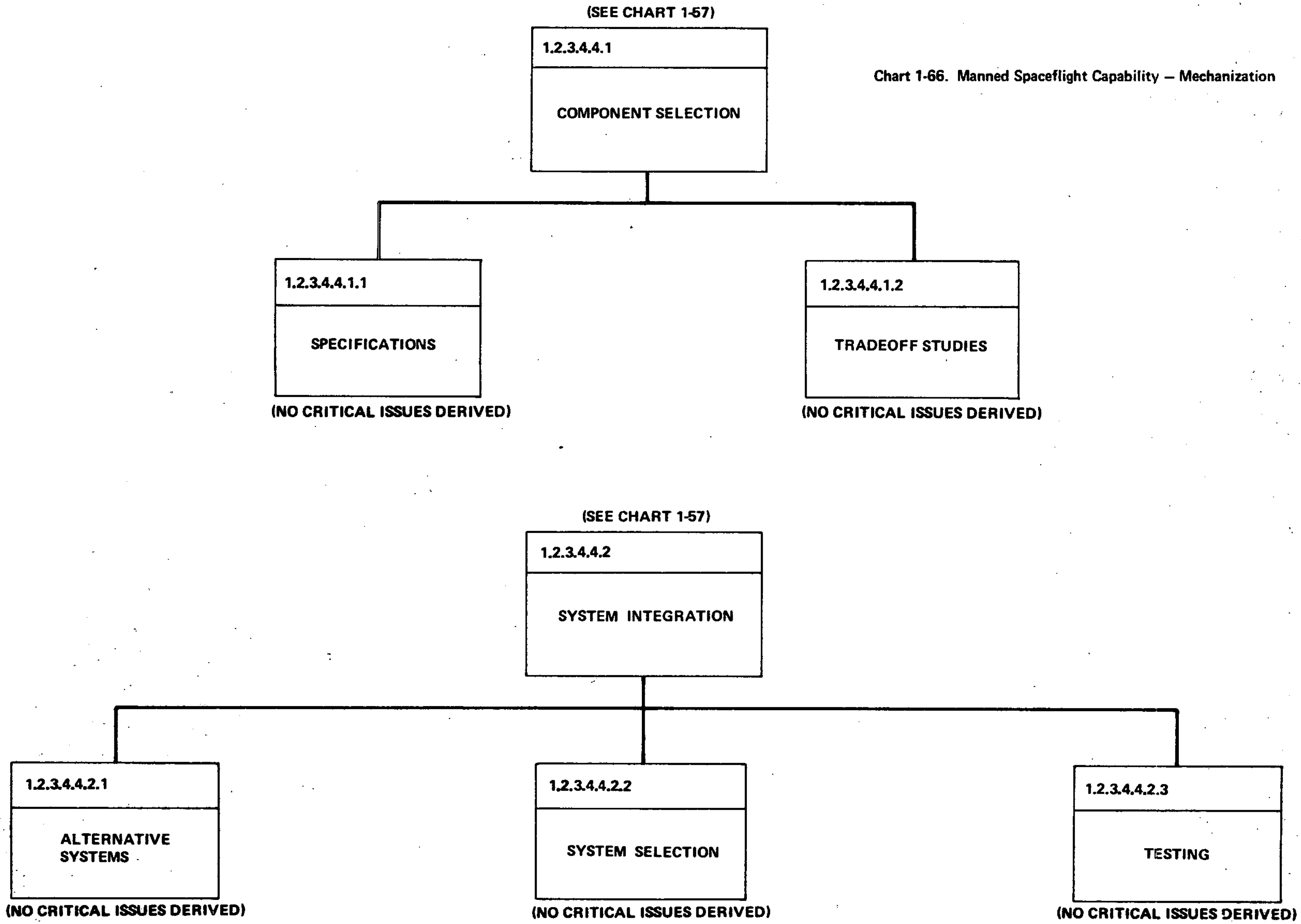


Chart 1-67. Manned Spaceflight Capability – Attitude and Position Sensors

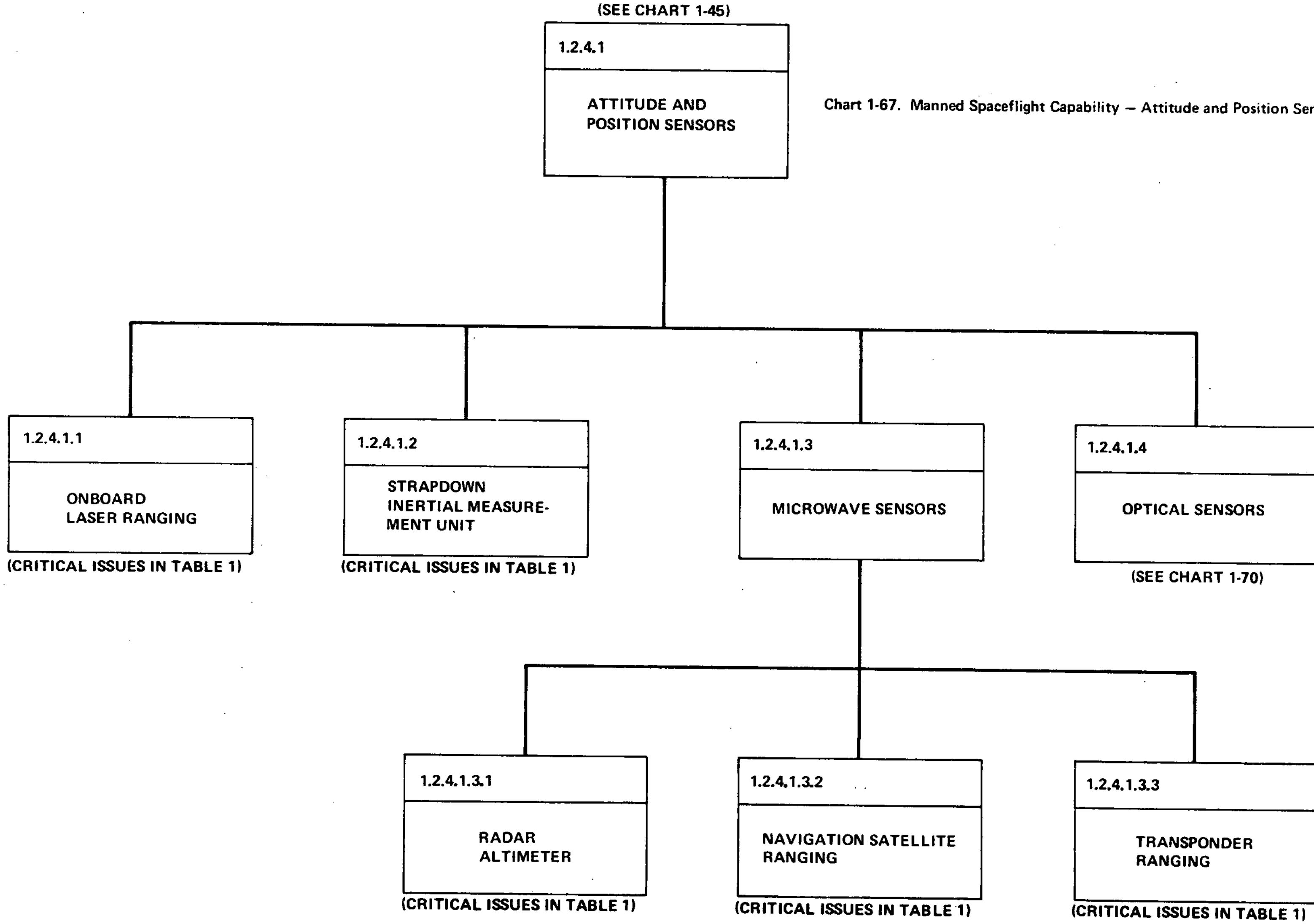


Chart 1-68. Manned Spaceflight Capability – Software

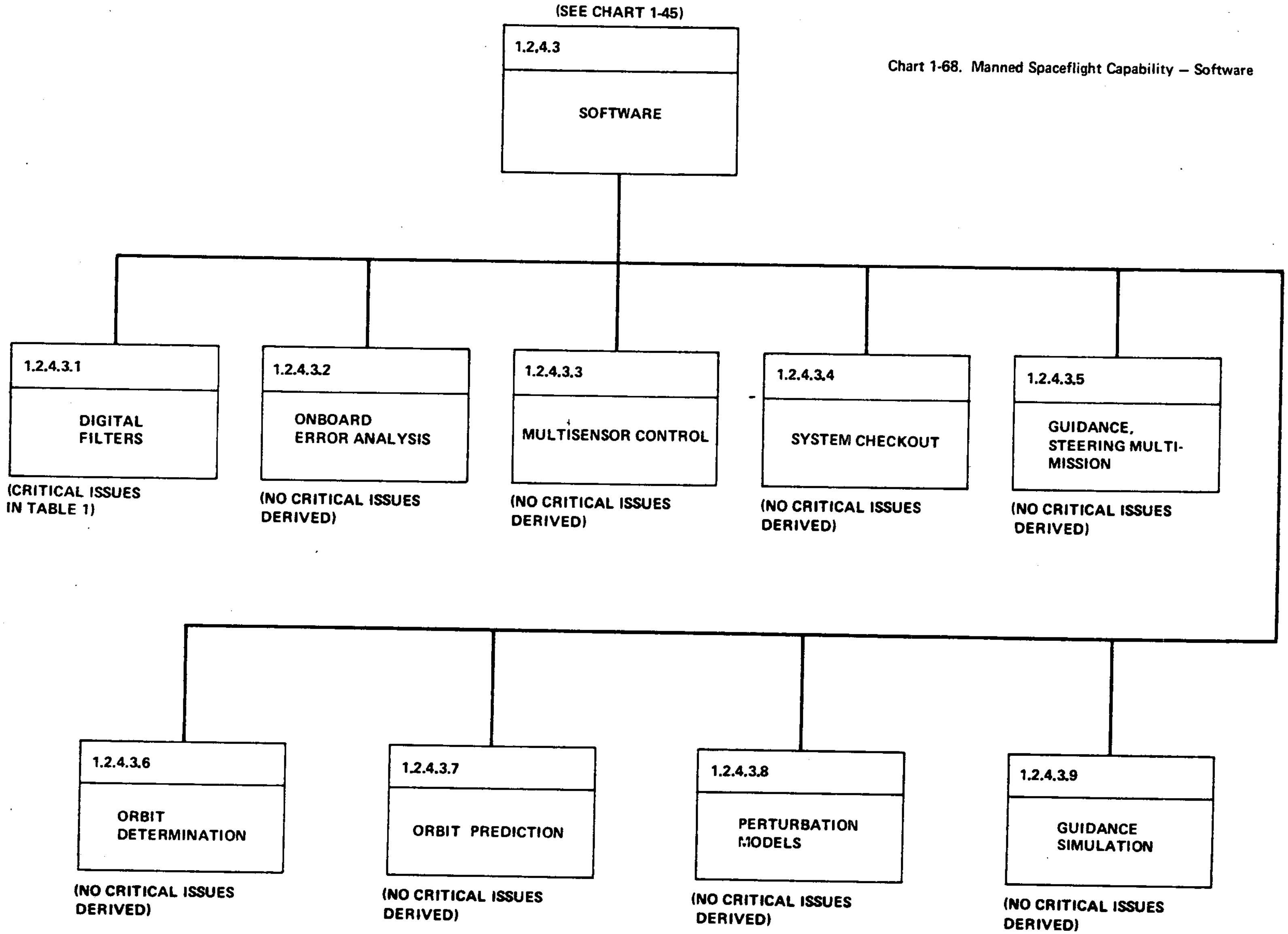
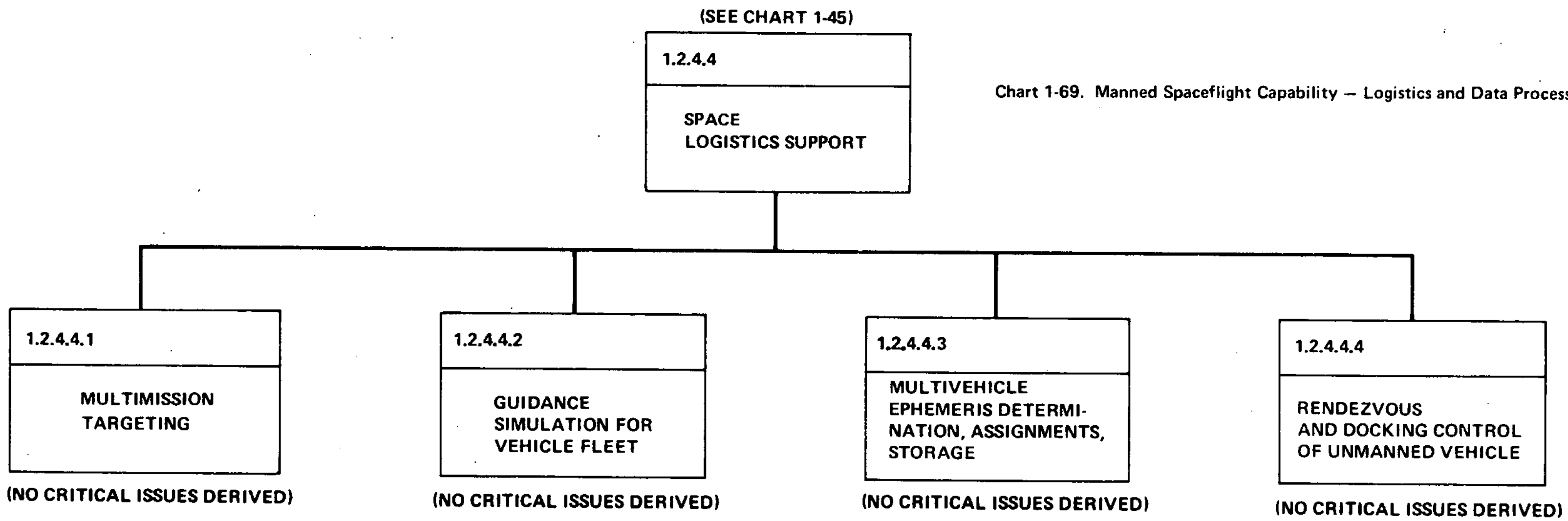


Chart 1-69. Manned Spaceflight Capability – Logistics and Data Processing



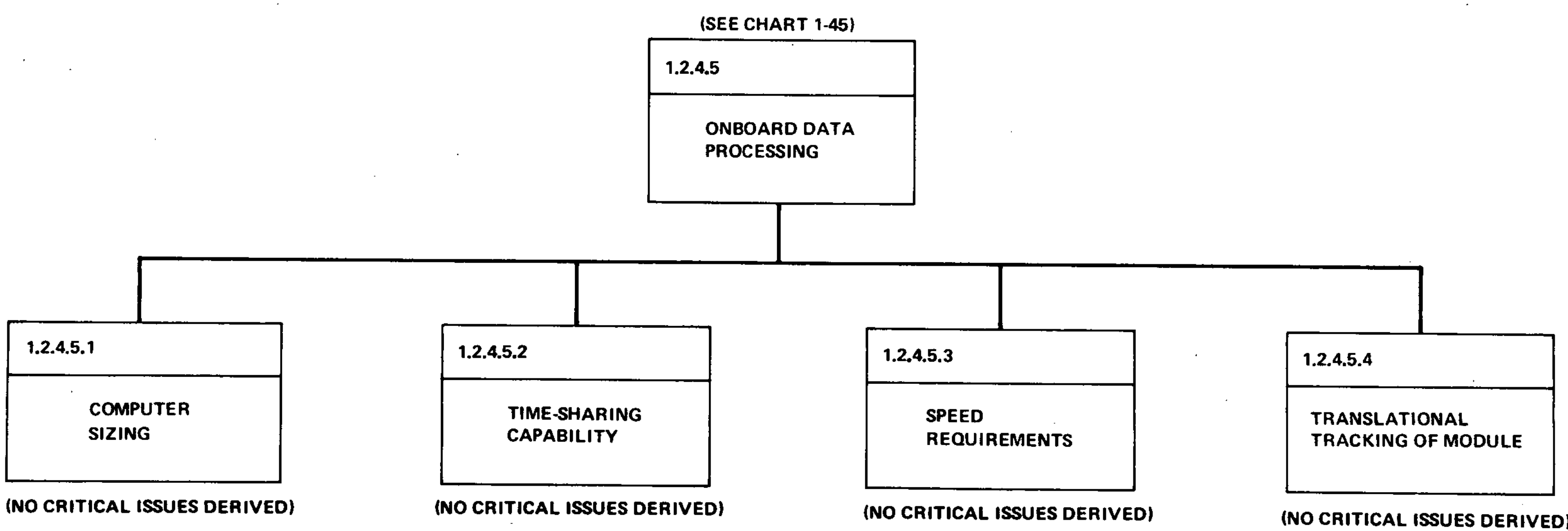


Chart 1-70. Manned Spaceflight Capability – Optical Sensors

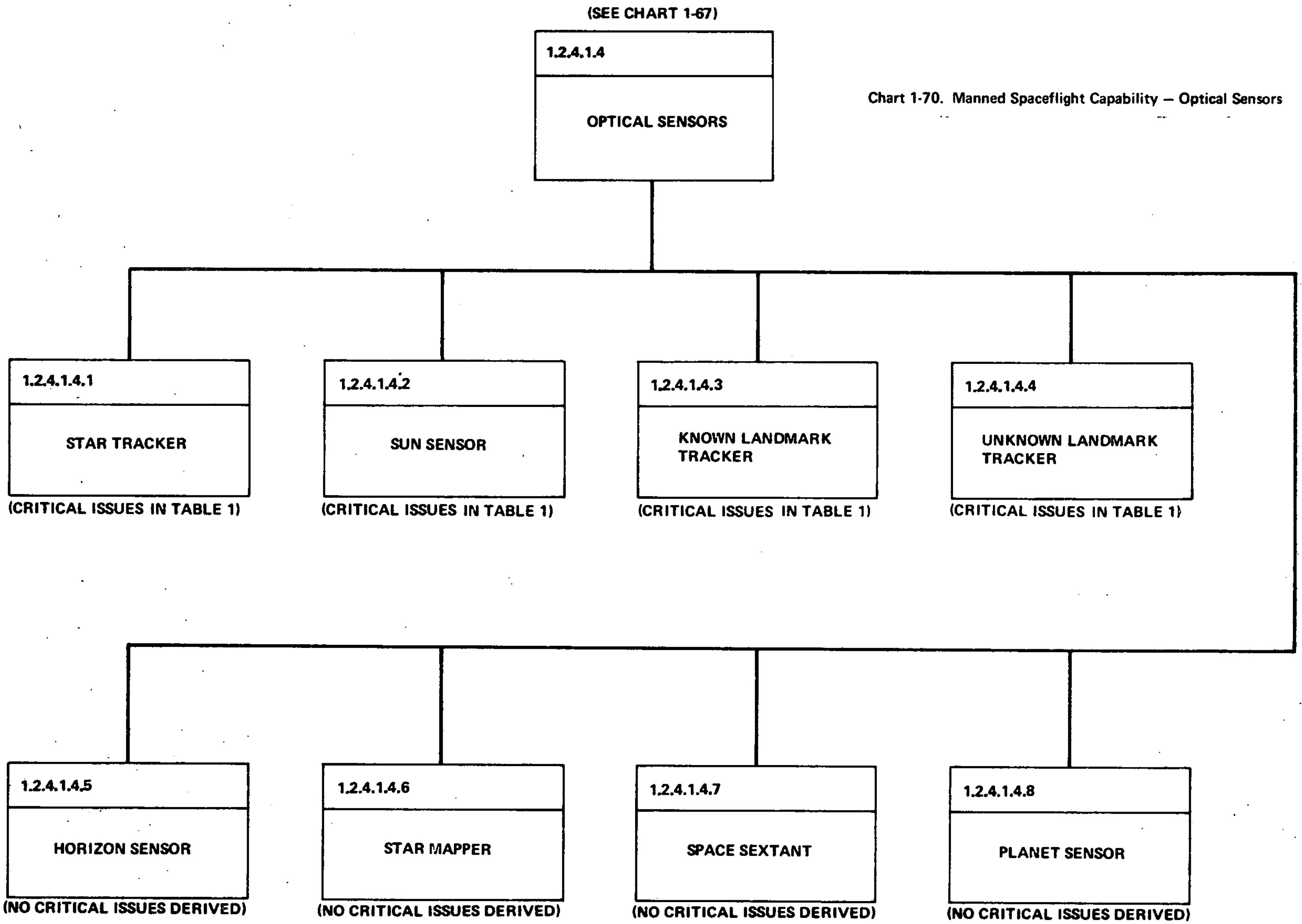


Chart 1-71. Manned Spaceflight Capability – Logistics, Resupply and Rescue

(SEE CHART 1-6)

1.3.1 SPACE LOGISTICS AND RESUPPLY

Objective: Develop and evaluate techniques for cargo transfer (solids and liquids), personnel transfer, space rescue, and data return (e.g., data capsules) for long duration space flight.

- 1.3.1.1 INTERFACES (SEE CHART 1-76)
- 1.3.1.2 OPERATIONS (SEE CHART 1-77)
- 1.3.1.3 DATA CAPSULES (CRITICAL ISSUES IN TABLE 1)
- 1.3.1.4 PERSONNEL
  - 1.3.1.4.1 MOBILITY AIDS (CRITICAL ISSUES IN TABLE 1)
  - 1.3.1.4.2 OPERATIONS SUPPORT (CRITICAL ISSUES IN TABLE 1)
- 1.3.1.5 RESCUE/EMERGENCY (SEE CHART 1-78)

Chart 1-72. Manned Spaceflight Capability – Maintenance, Repair and Retrofit

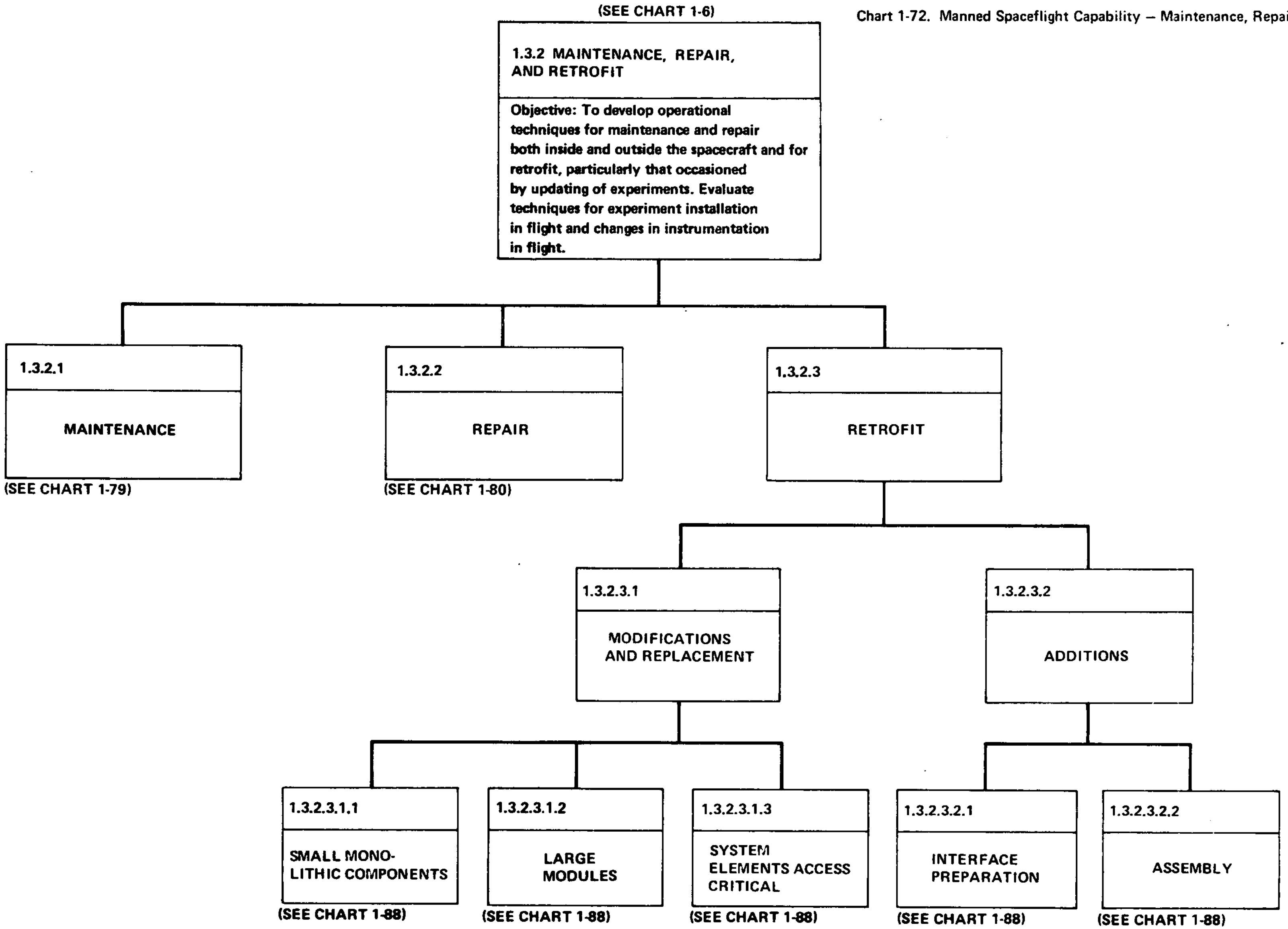


Chart 1-73. Manned Spaceflight Capability – Assembly and Deployment

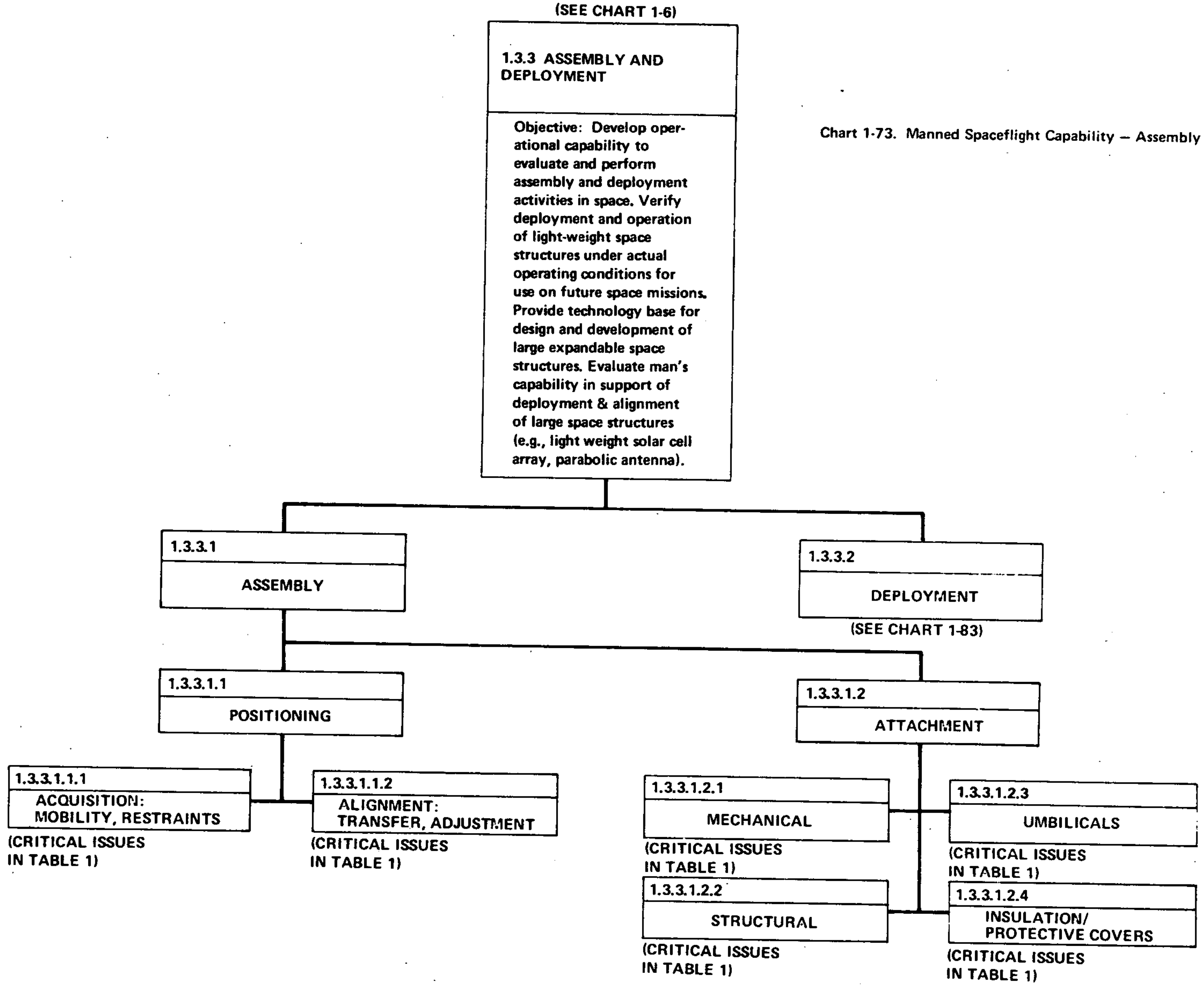


Chart 1-74. Manned Spaceflight Capability – Module Mission Operations

(SEE CHART 1-6)

1.3.4 MODULE OPERATIONS

Objective: Develop and evaluate methods for control, monitoring, connecting, and communicating with unmanned vehicles launched from a manned space station or independently launched from the ground and operating in conjunction with a manned space station. Develop and evaluate techniques for rendezvous and docking, remote control and manipulation, communications and power (e.g., demonstrate the feasibility of using microwave or laser energy for wireless transfer of power from space station to an unmanned substation).

- 1.3.4.1 DATA MANAGEMENT
  - 1.3.4.1.1 DATA COLLECTION, STORAGE, AND TRANSMISSION (SEE CHART 1-50)
  - 1.3.4.1.2 DATA REDUCTION, RETRIEVAL, AND PRESENTATION (SEE CHART 1-50)
- 1.3.4.2 CONTROL AND GUIDANCE (SEE CHART 1-84)
- 1.3.4.3 ELECTRICAL POWER
  - 1.3.4.3.1 SOLAR CELLS AND BATTERY (SEE CHART 1-52)
  - 1.3.4.3.2 FUEL CELL, AND CHEMICAL DYNAMICS (SEE CHART 1-43)
  - 1.3.4.3.3 NUCLEAR POWER SYSTEMS (SEE CHART 1-43
  - 1.3.4.3.4 POWER CONDITIONING, AND DISTRIBUTION (SEE CHART 1-43)
- 1.3.4.4 COMMUNICATIONS
  - 1.3.4.4.1 EMERGENCY COMMUNICATION (SEE CHART 1-46)
  - 1.3.4.4.2 MODULES TO/ FROM SPACECRAFT (SEE CHART 1-46)
  - 1.3.4.4.3 MODULES TO/FROM GROUND (SEE CHART 1-46)

Chart 1-75. Manned Spaceflight Capability — Vehicle Support Mission Operations

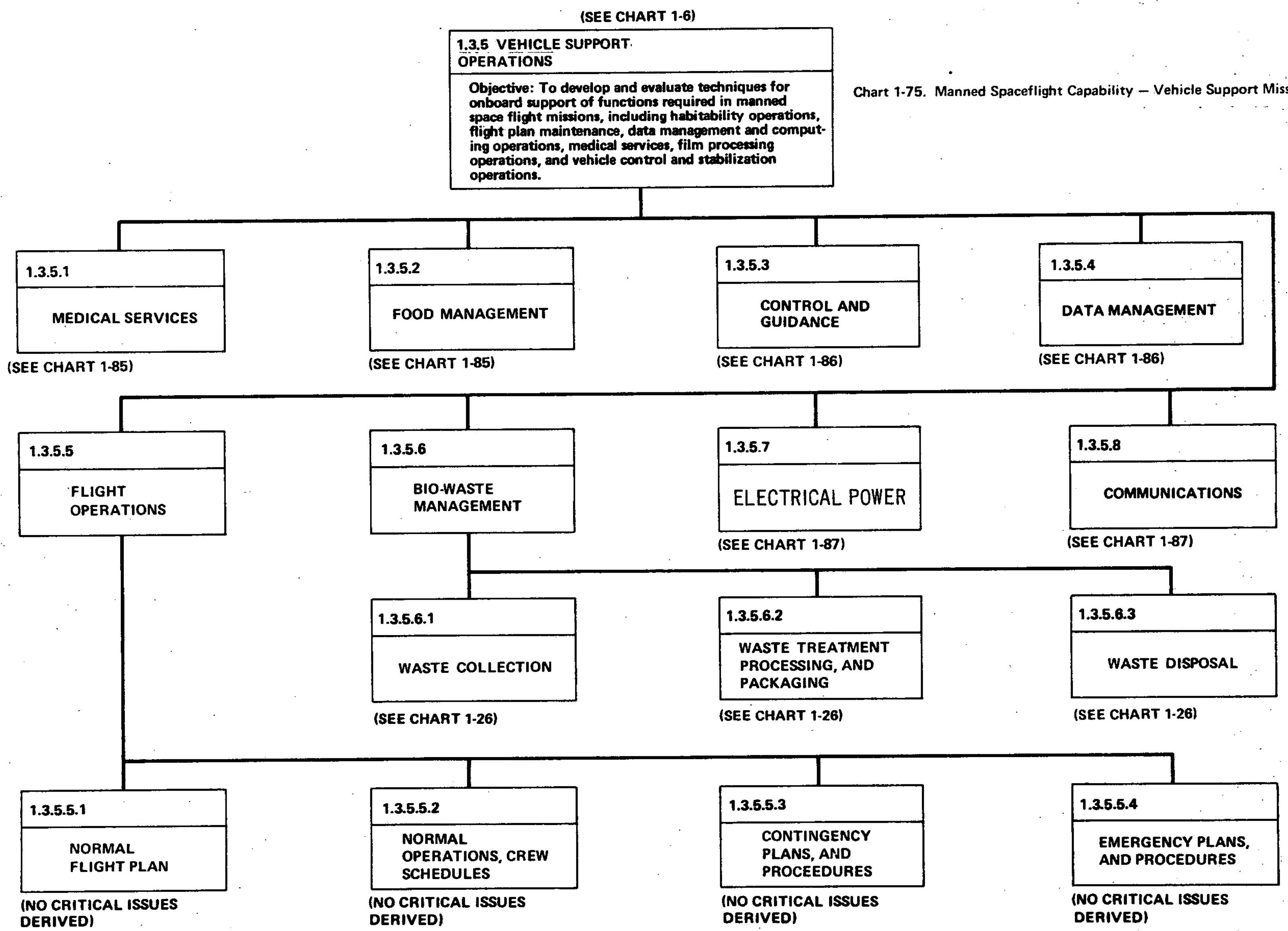


Chart 1-76. Manned Spaceflight Capability – Interfaces

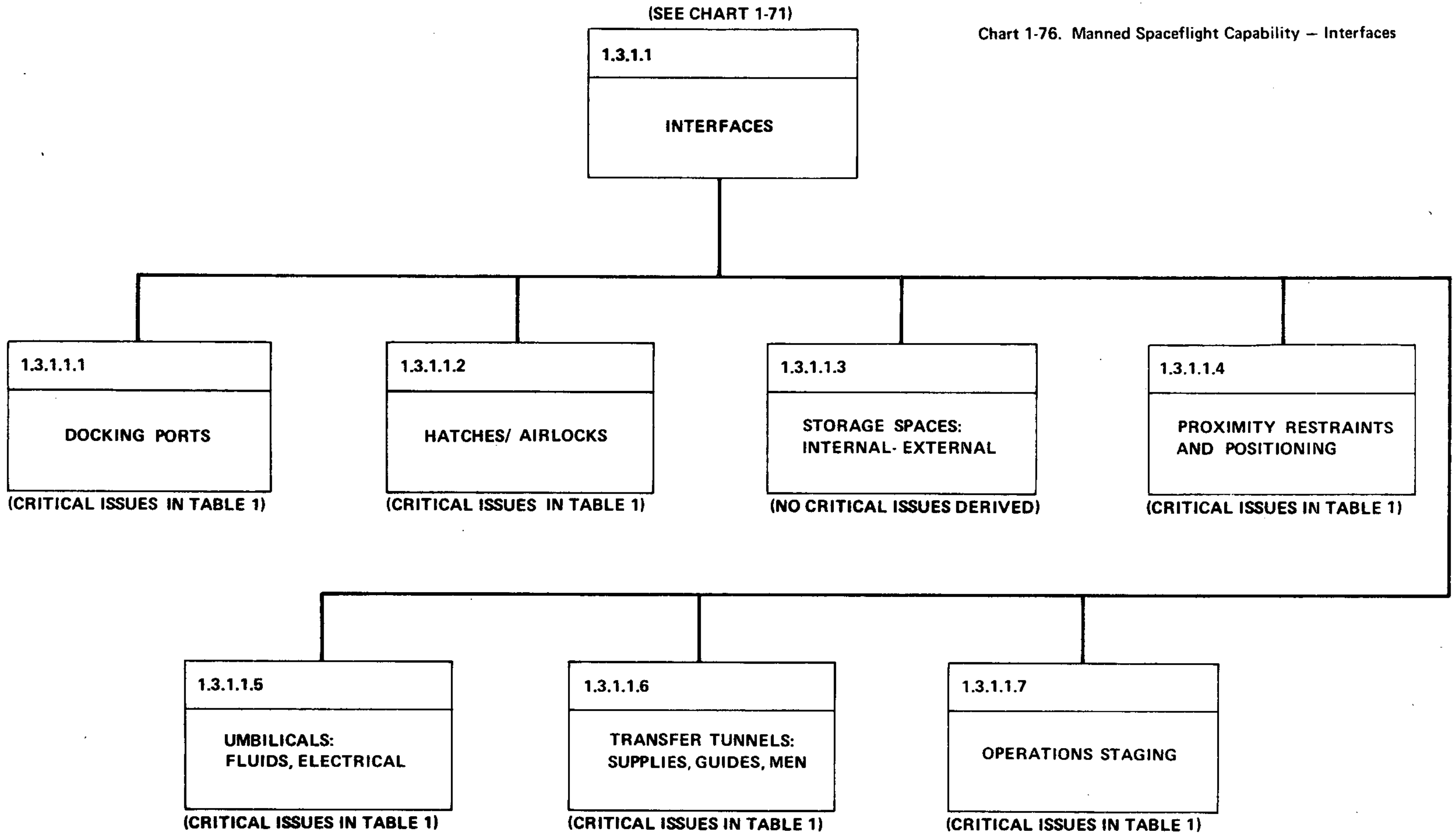


Chart 1-77. Manned Spaceflight Capability – Operations

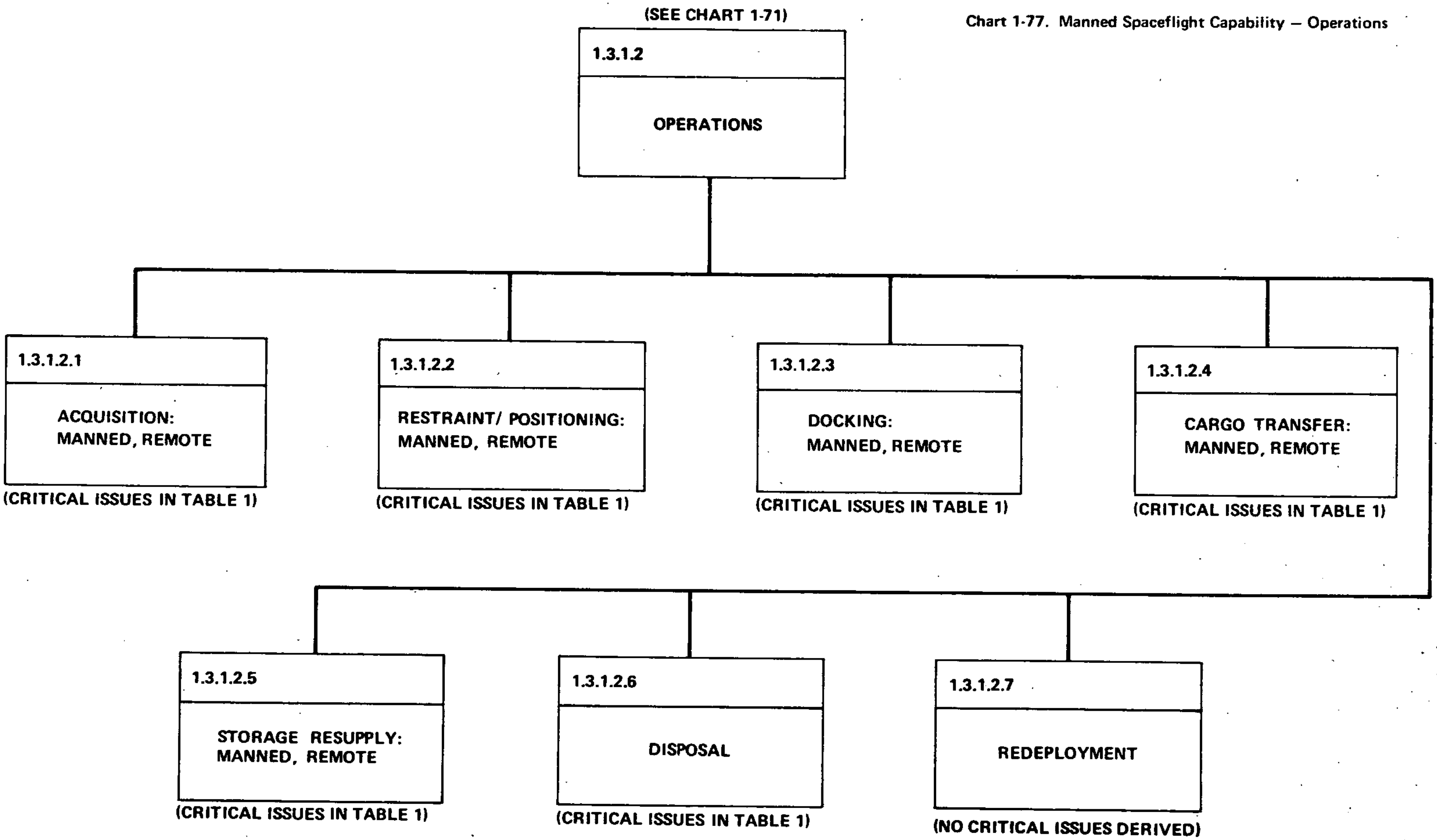


Chart 1-78, Manned Spaceflight Capability – Rescue / Emergency

(SEE CHART 1-71)

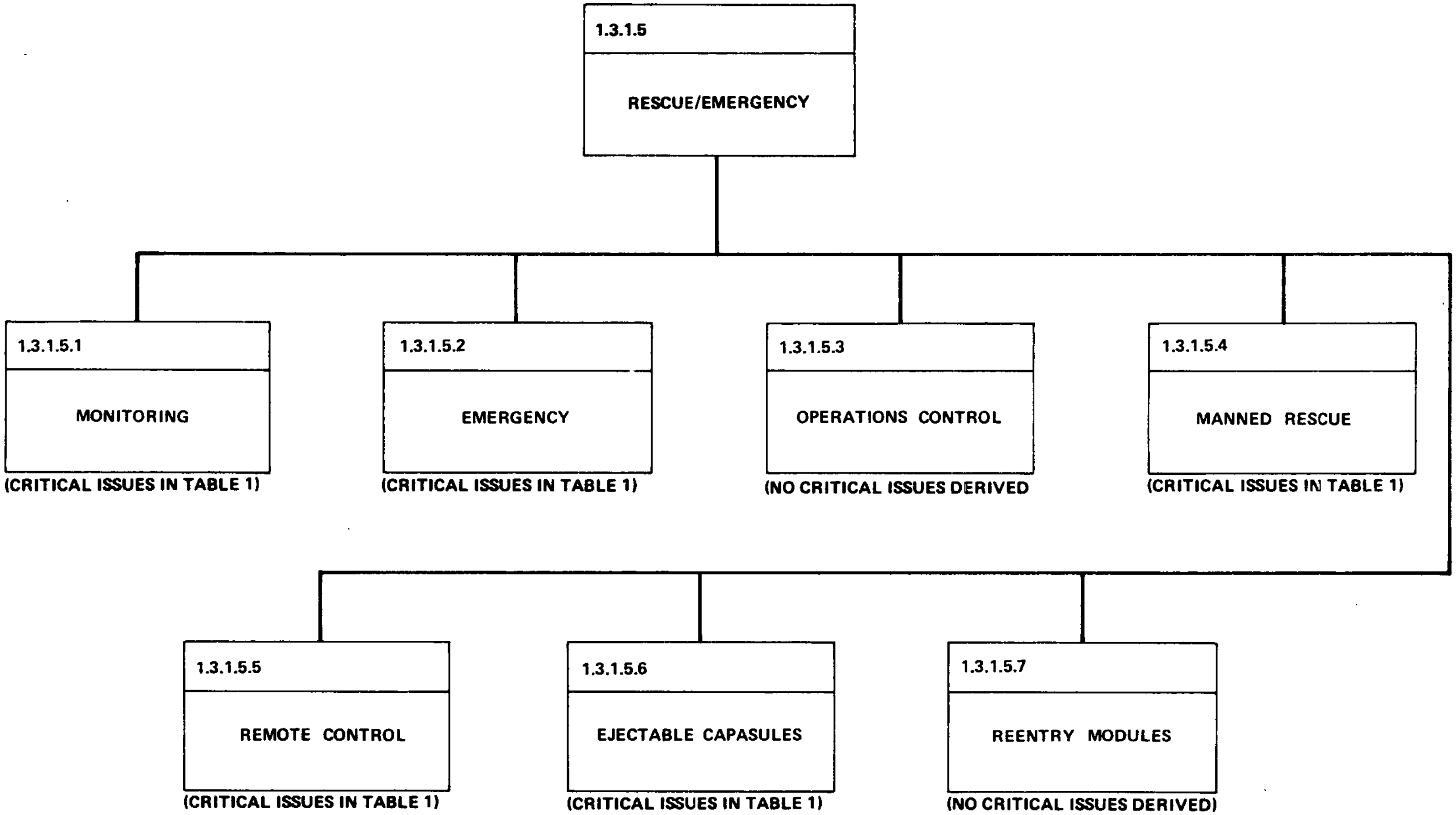


Chart 1-79. Manned Spaceflight Capability – Maintenance

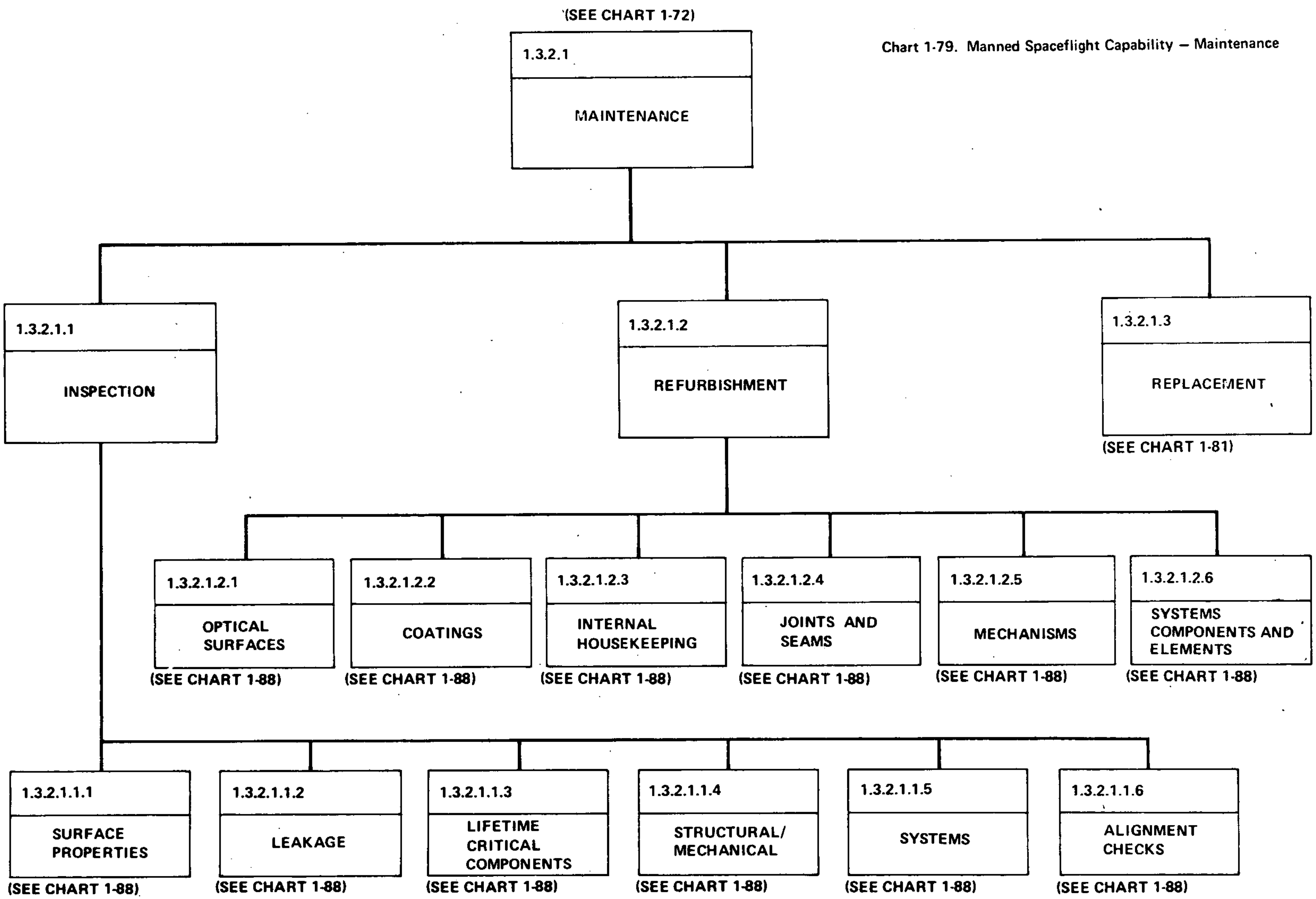


Chart 1-80. Manned Spaceflight Capability – Repair

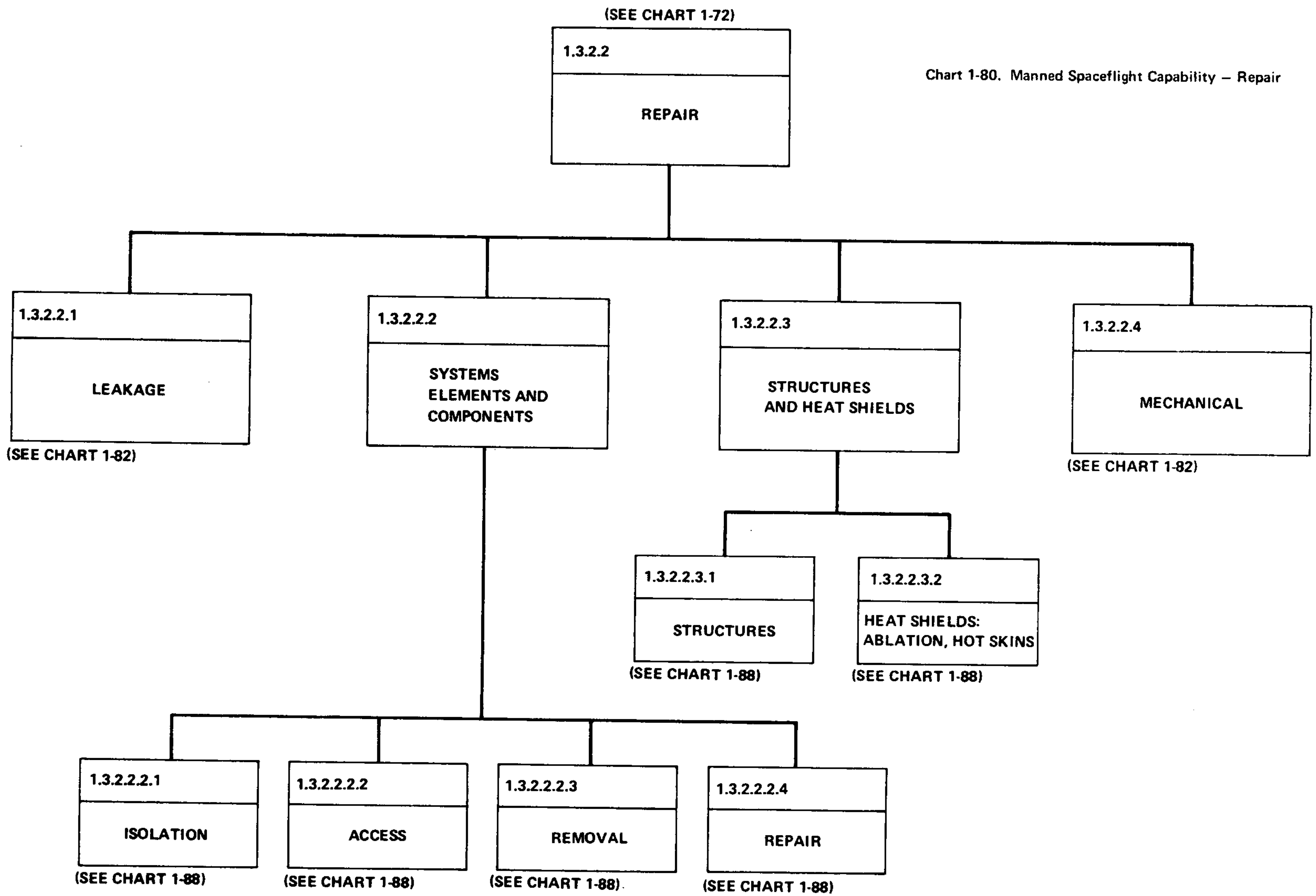


Chart 1-81. Manned Spaceflight Capability – Replacement

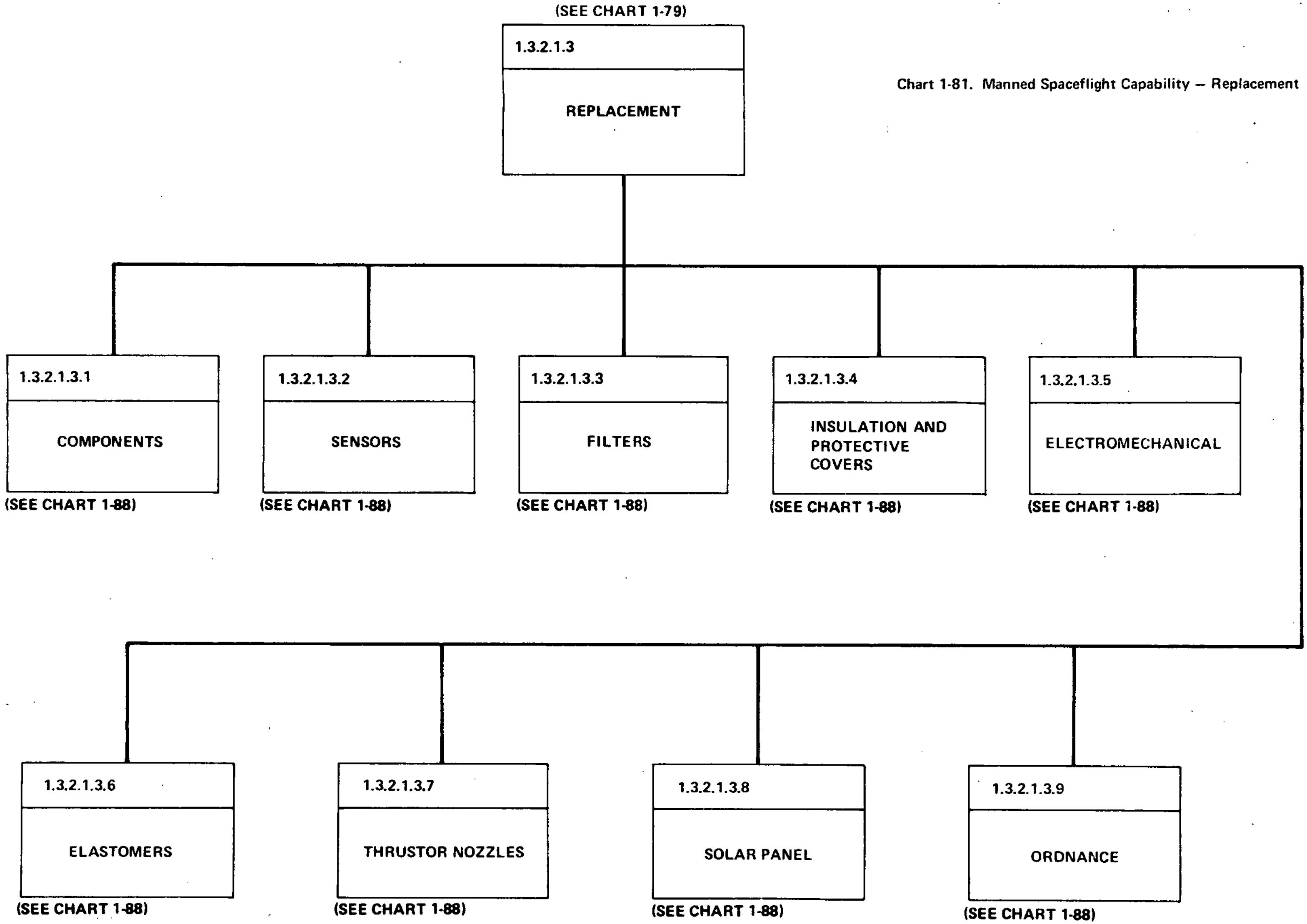
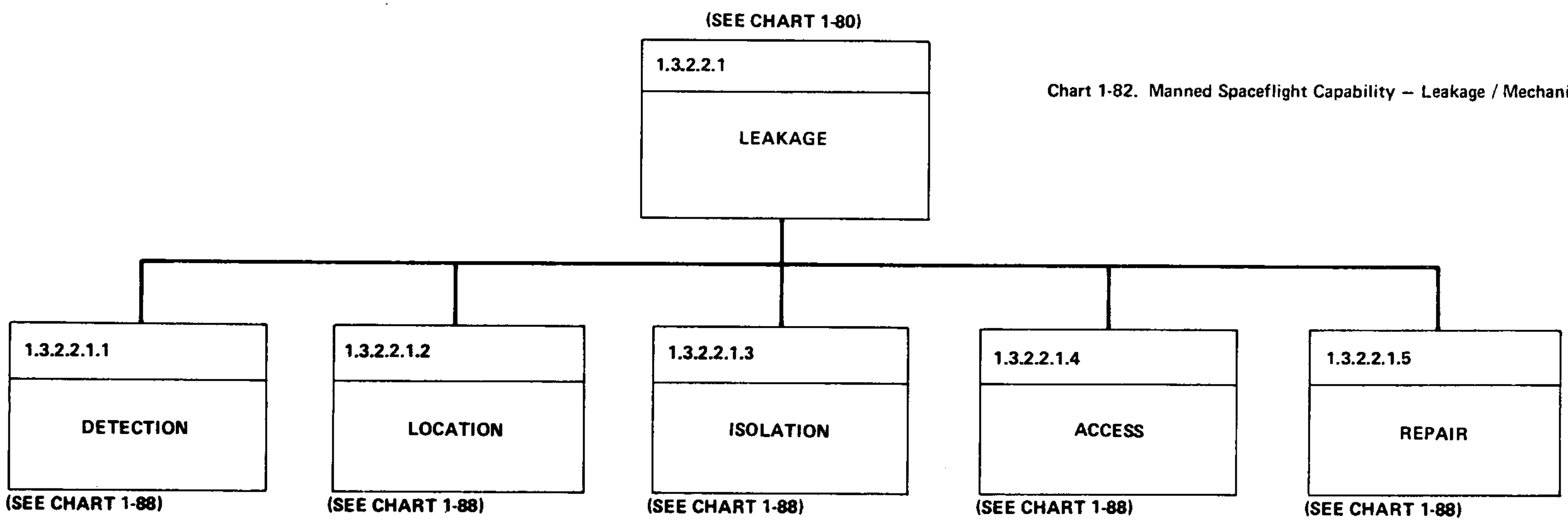


Chart 1-82. Manned Spaceflight Capability – Leakage / Mechanical



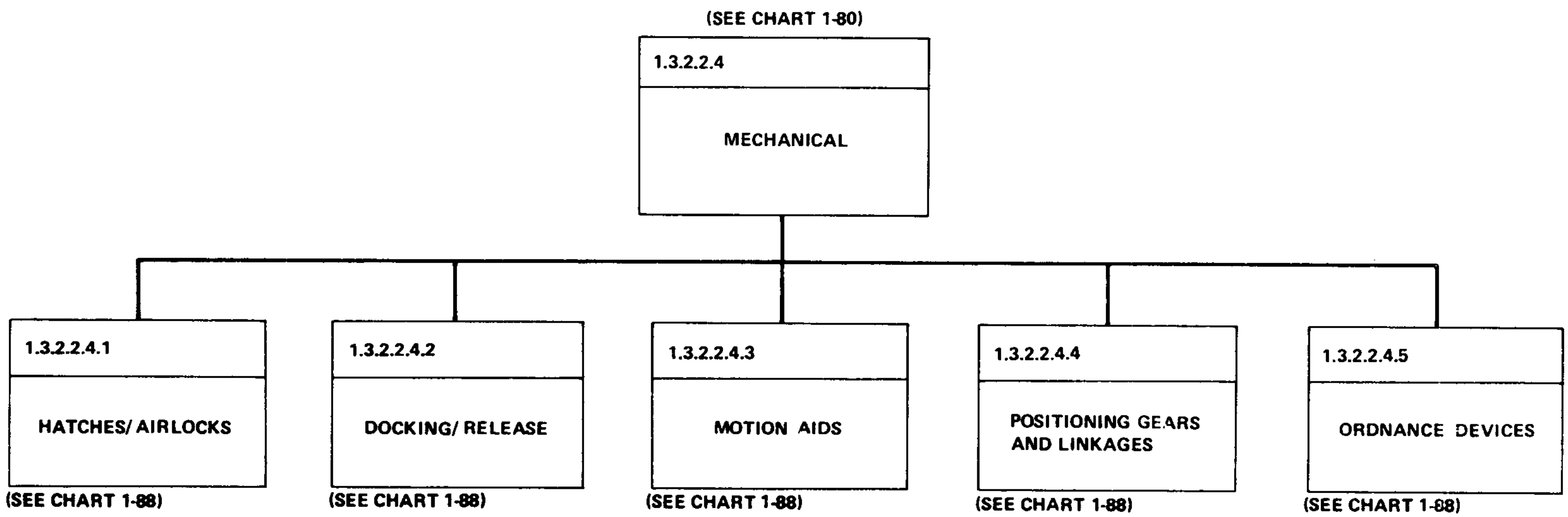


Chart 1-83. Manned Spaceflight Capability – Deployment

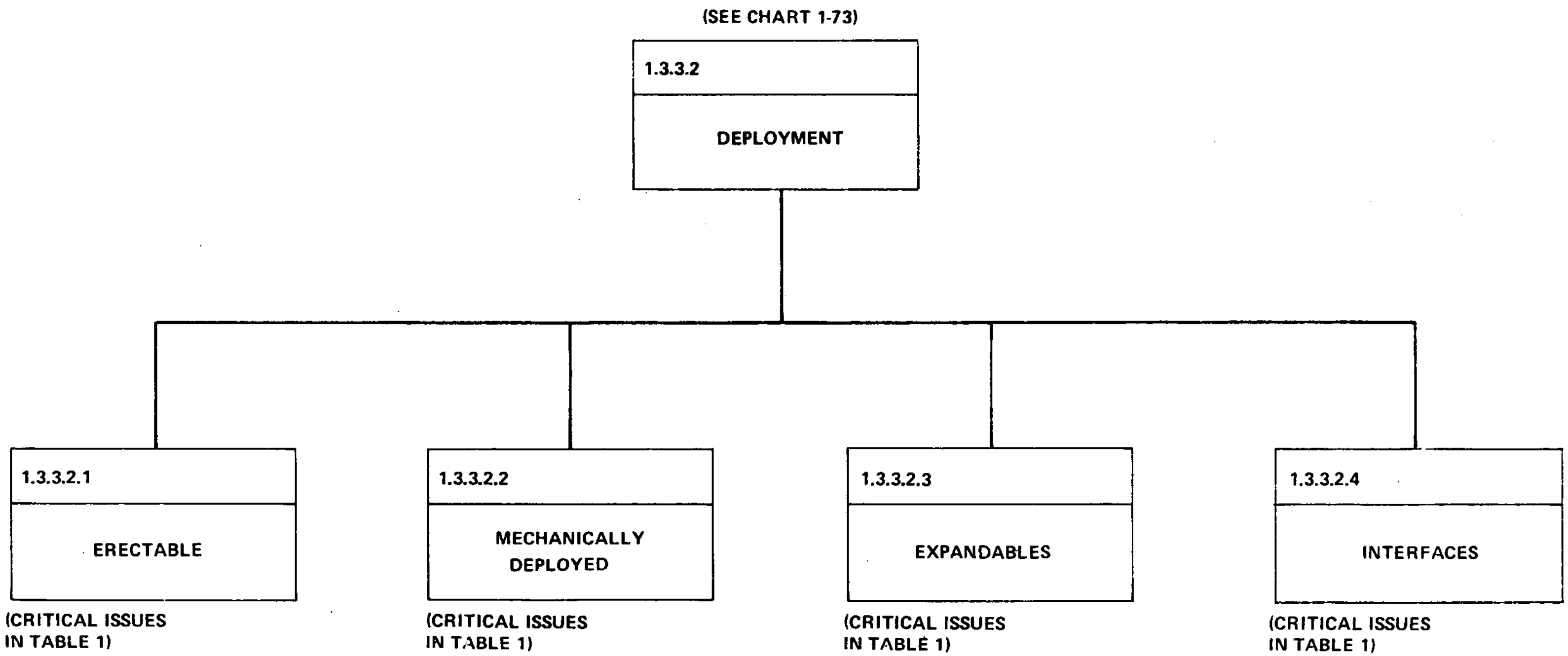


Chart 1-84. Manned Spaceflight Capability – Control

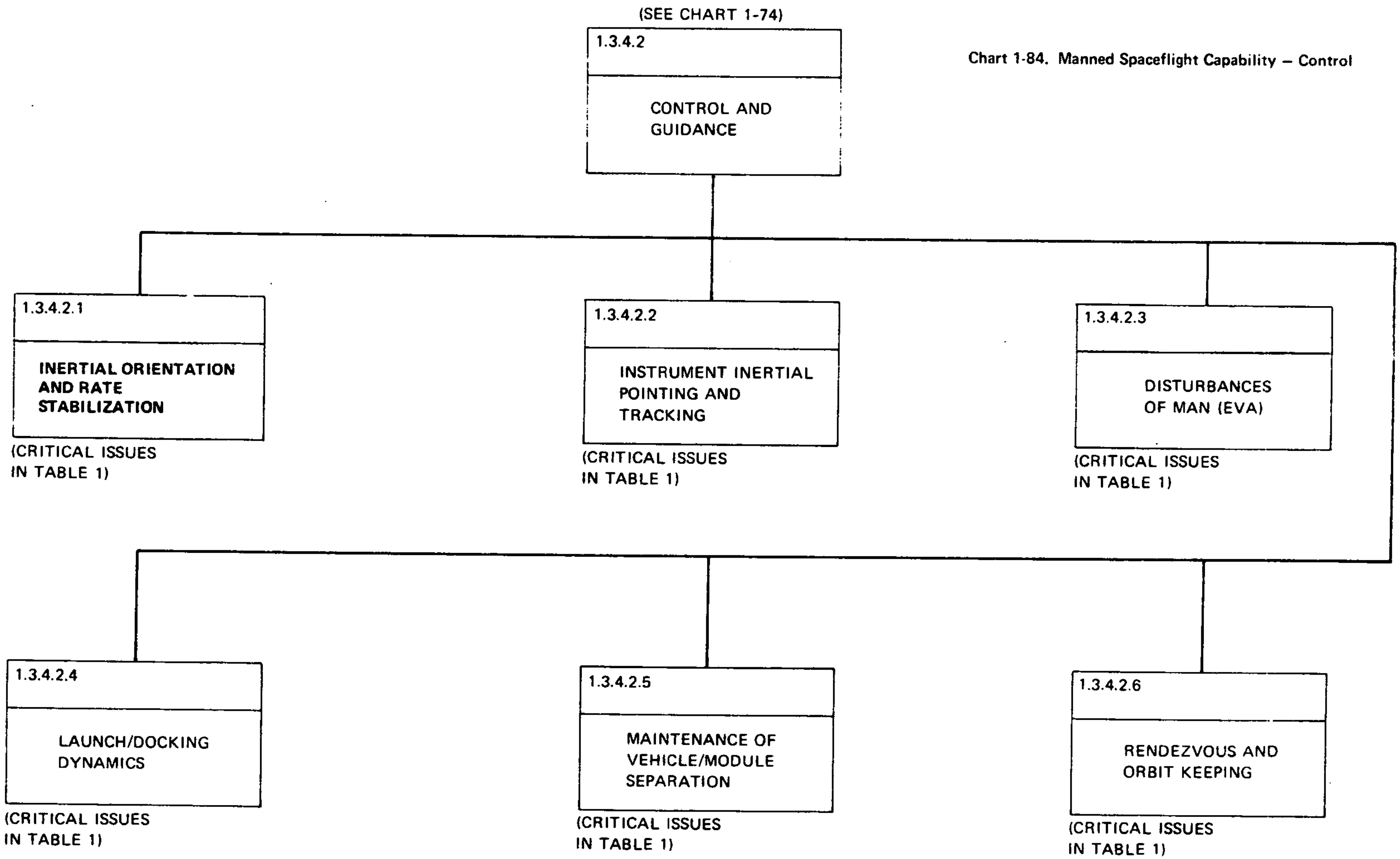
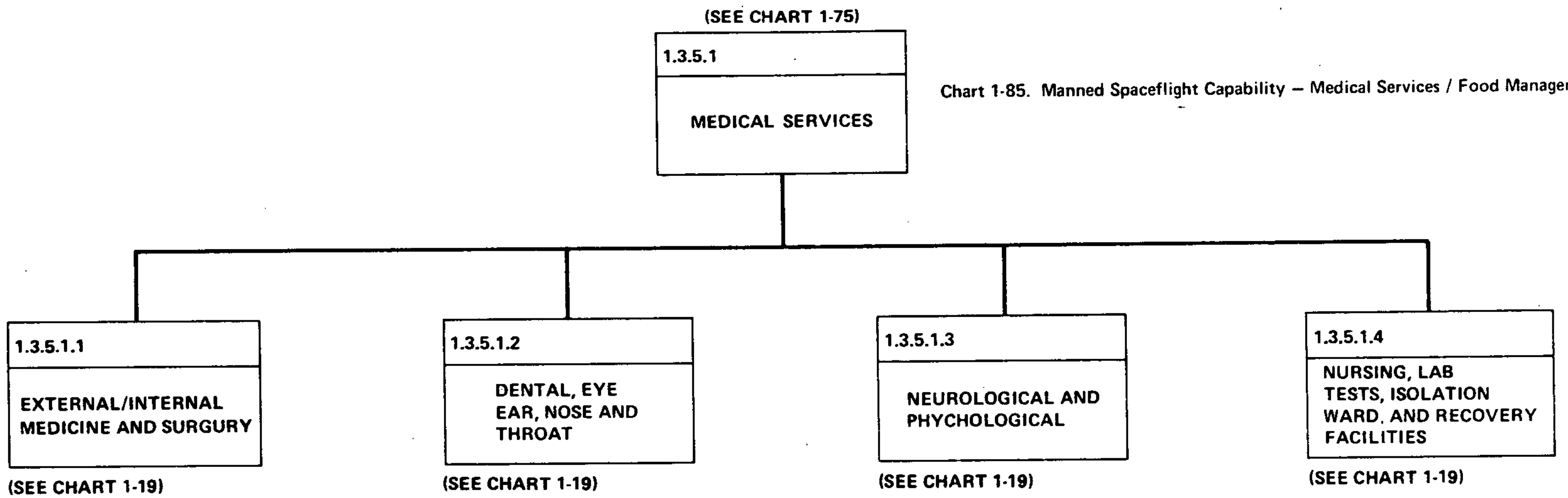


Chart 1-85. Manned Spaceflight Capability – Medical Services / Food Management



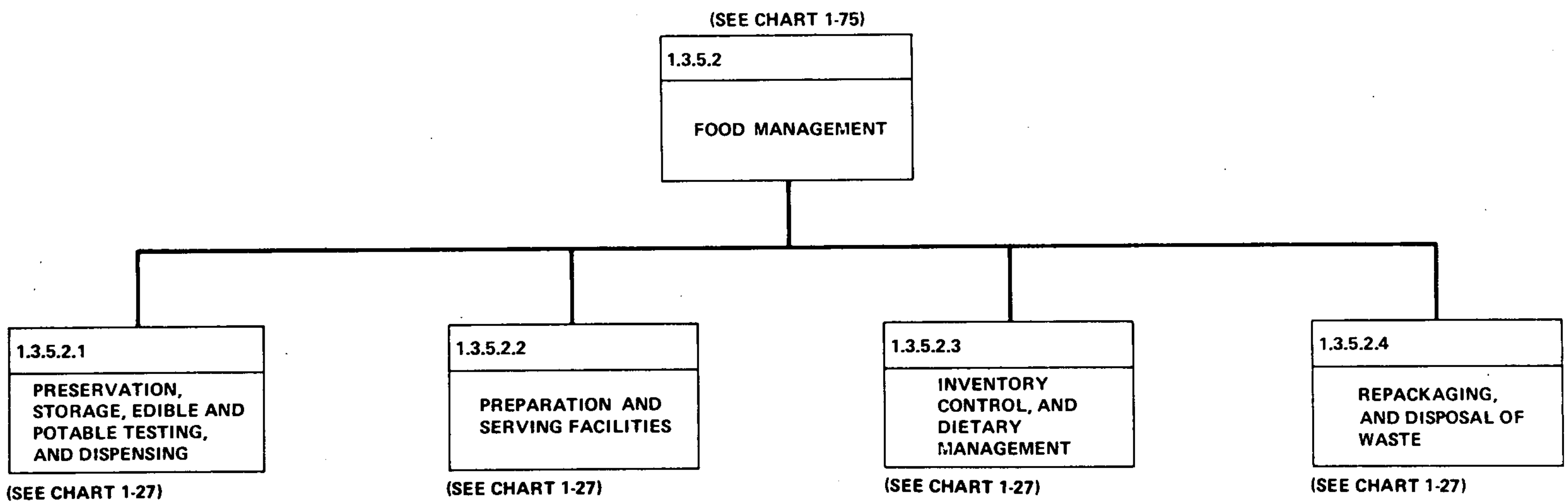


Chart 1-86. Manned Spaceflight Capability – Data Management / Control

(SEE CHART 1-75)

- 1.3.5.4. DATA MANAGEMENT
  - 1.3.5.4.1 COMPUTER SYSTEMS OPERATION AND MANAGEMENT (SEE CHART 1-47)
  - 1.3.5.4.2 DATA COLLECTION, REDUCTION, RETRIEVAL, AND PRESENTATION (SEE CHART 1-50)
  - 1.3.5.4.3 DATA STORAGE AND TRANSMISSION (SEE CHART 1-42)
  - 1.3.5.4.4 DATA MANAGEMENT SCHEDULING: PRIMARY VEHICLE AND MODULE(S) (SEE CHART 1-42)

(SEE CHART 1-75)

- 1.3.5.3 CONTROL AND GUIDANCE
  - 1.3.5.3.1 INERTIAL ORIENTATION AND RATE STABILIZATION (CRITICAL ISSUES IN TABLE 1)
  - 1.3.5.3.2 INSTRUMENT INERTIAL POINTING AND TRACKING (CRITICAL ISSUES IN TABLE 1)
  - 1.3.5.3.3 TRANSLATIONAL TRACKING OF MODULE (CRITICAL ISSUES IN TABLE 1)
  - 1.3.5.3.4 MONITORING MODULE OPERATIONS (CRITICAL ISSUES IN TABLE 1)
  - 1.3.5.3.5 CONTROL OF MODULE EXPERIMENTS, AND ENVIRONMENT (NO CRITICAL ISSUES DERIVED)

Chart 1-87. Manned Spaceflight Capability – Electrical Power/Communications

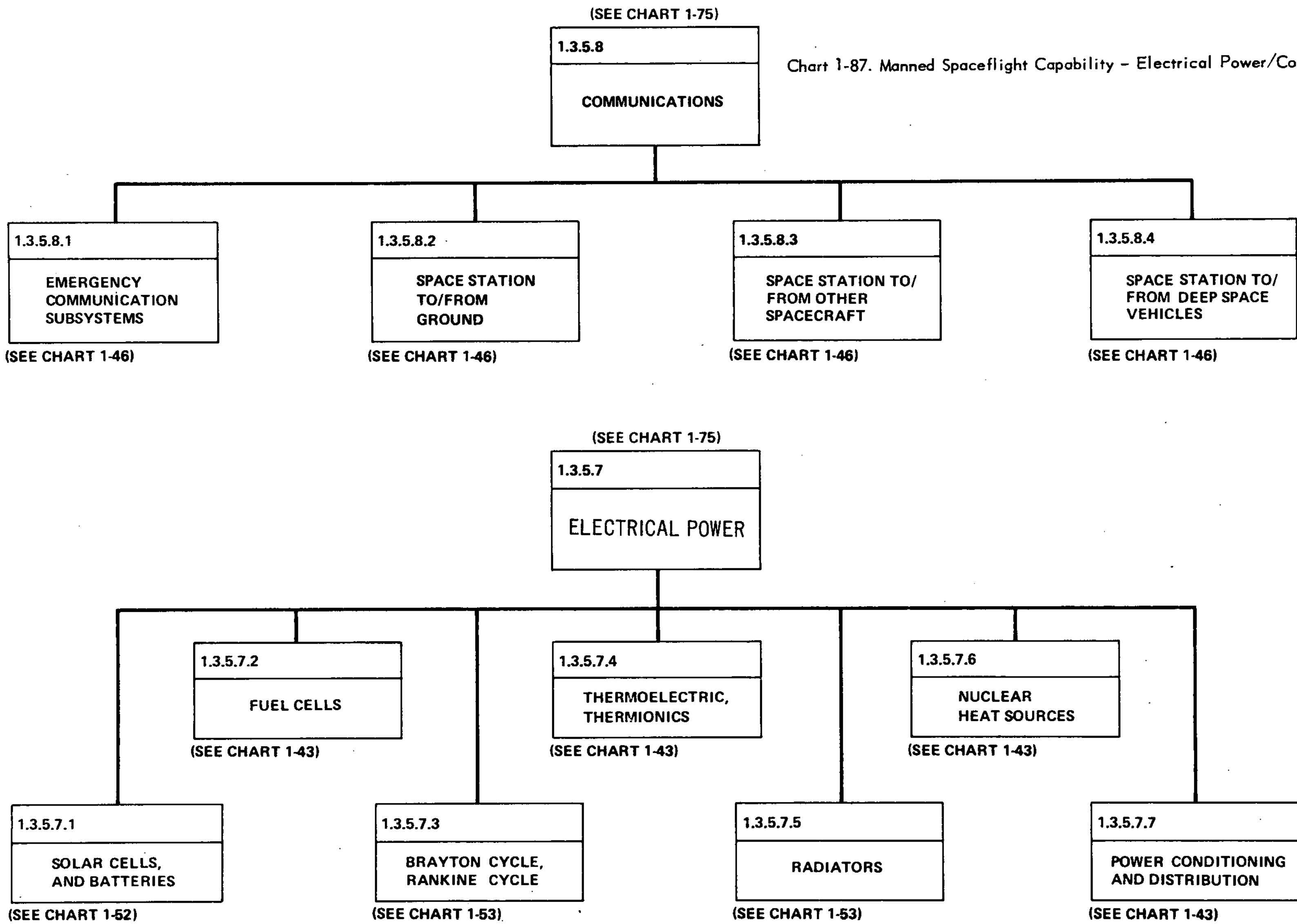


Chart 1-88. Manned Spaceflight Capability – Maintenance, Repair and Retrofit: Functional Elements

(SEE CHART 1-79)

1.3.2
MAINTENANCE, REPAIR AND RETROFIT: FUNCTIONAL ELEMENTS

Note: This chart parallels Chart 1-72 and its derivatives and outlines the functions of man related to maintenance, repair and retrofit. Critical issues are found in the charts which follow

- **1.3.2.1** EFFECTIVENESS OF MAN'S SENSORY PERCEPTIONS
  (SEE CHART 1-89)
- **1.3.2.3** ALLOCATIONS OF TIME AND ENERGY FOR OPERATIONS
  (CRITICAL ISSUES IN TABLE 1)
- **1.3.2.5** CONTROL OF OPERATIONS HAZARDS AND RESIDUALS
  (CRITICAL ISSUES IN TABLE 1)
- **1.3.2.2** LIMITATIONS OF ACCESSIBILITY AND MOBILITY ON MAN
  (SEE CHART 1-90)
- **1.3.2.4** DEVELOPMENT TOOLS AND AIDS
  (CRITICAL ISSUES IN TABLE 1)
- **1.3.2.6** OPERATIONS PLANNING
  (CRITICAL ISSUES IN TABLE 1)

Chart 1-89. Manned Spaceflight Capability – Sensory Perceptions

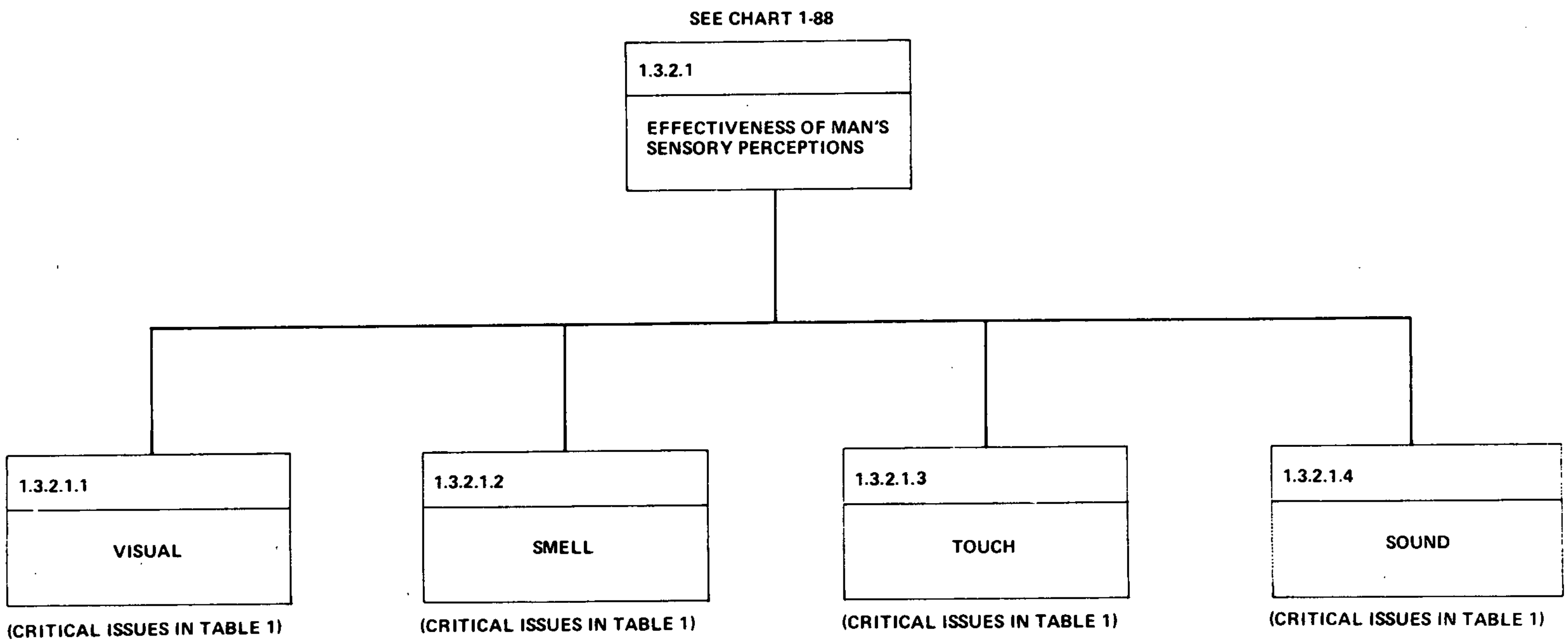
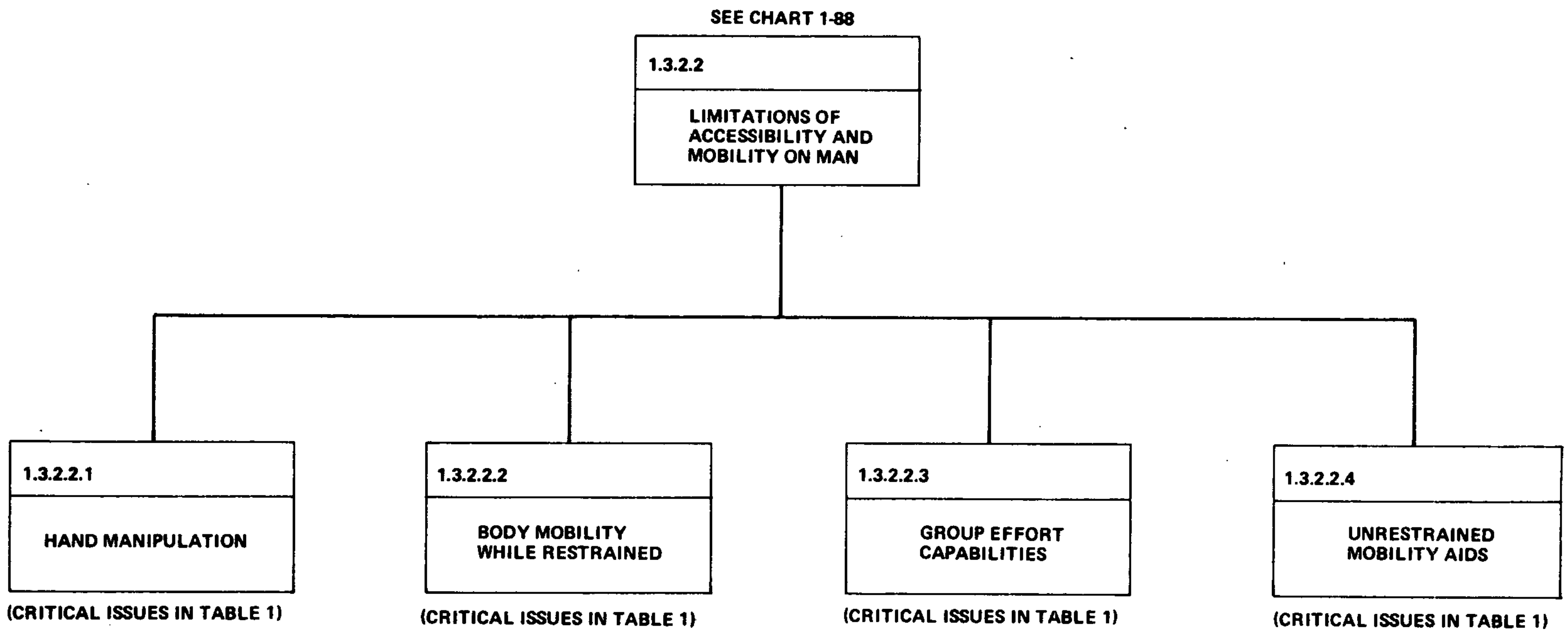


Chart 1-90. Manned Spaceflight Capabilities – Accessibility and Mobility Limitations



APPENDIX B

CRITICAL ISSUES

MANNED SPACEFLIGHT CAPABILITY

B-1-1

Appendix B
INTRODUCTION

This appendix presents the series of 3,800 critical issues that comprise the principal result of the organized overview analysis of objectives for the six scientific and technical disciplines. The organized overview is described in Section 2 and graphically displayed in the charts contained in Appendix A.

In order to maintain the traceable indexing system carried through the charts shown in Appendix A, the numbers are repeated as major headings in Appendix B. Each critical issue thereby retains identity with the objectives and subobjectives from which it was derived.

The results of further analysis of the critical issues during the latter phases of the study are combined with the tabulation in this appendix by entering a code in the margin of the page, specifying the eventual disposition action. Table B-1 explains the code used for this assignment of critical issues.

In using Table B-1 to trace out the disposition, it is helpful to note that the principal consideration is whether or not the critical issue is addressed in at least one research cluster. In cases where this has occurred, the identifying serial number of the research cluster is used as the code. The alternative (2-letter) codes refer to categorical assignments of critical issues not included in the research cluster descriptions.

A summary of the disposition of the 3,800 critical issues in the six disciplines, according to the coding protocol of Table B-1, is presented in Table B-2.

Gaps in the sequence of critical issue numbers in Appendix B represent scientific and technical areas that were considered in the study but for which no critical issues were derived.

Table B-1

CODE FOR DISPOSITION OF CRITICAL ISSUES

X-AB-YY	Addressed in Research Cluster No. X-AB-XY The first number (X) indicates the scientific or technical discipline, i.e., 1 - Manned Spaceflight Capability 2 - Space Biology 3 - Space Astronomy 4 - Space Physics 5 - Communications and Navigation 6 - Earth Observations The one- or two-letter code (AB) indicates the subdiscipline area, e.g., BR - Behavioral Research PP - Plasma Physics Laboratory A/F - Agriculture, Forest, and Range Resources The final number (YY) is a sequence number within the subdiscipline. Thus, 4-PP-3 is the third research cluster in the Plasma Physics Laboratory subdiscipline of the Space Physics discipline.
PS	Eliminated by Preliminary Screening Critical issue considered to be essentially peripheral to the scope of Earth orbital research. These issues were included in the report for the ideas that they might stimulate, but were not analyzed further.
NS	Eliminated: Not an Earth Orbital Research Candidate Critical issue judged to be more appropriate to research based elsewhere—terrestrial, sub-orbital, interplanetary trajectories, extraterrestrial bodies, etc.—after considering the advantages and disadvantages of various orbits and of the space environment.
UM	Eliminated: Not a Manned Earth Orbital Research Candidate Critical issue judged to be better suited to automated spacecraft than to manned Earth orbital research facilities, due either to the inability of man to contribute meaningfully to the research or to detrimental effects of man's presence.

Table B-1

CODE FOR DISPOSITION OF CRITICAL ISSUES (Continued)

OP	Eliminated: Covered in Ongoing Programs Critical issue whose research requirements are expected to be satisfied from the results of programs already in progress or firmly planned.
AC	Deferred, Due to Requirements for Advanced Concepts Critical issue for which no experimental approach is currently available, or for which advanced study or advanced ground-based developments should precede further programmatic analysis.
MS, SB, SA, SP, CN, or EO	Principally Concerned with Another Discipline Critical issue included in the organized overview analysis of a given discipline for the sake of completeness, but which is actually more germain to another discipline (indicated by symbol) and is analyzed further in that discipline.

Table B-2

DISPOSITION OF CRITICAL ISSUES

Code \ Discipline	Manned Spaceflight Capability	Space Biology	Space Astronomy	Space Physics	Communications and Navigation	Earth Observations	Totals
In Research Cluster Cluster (X-AB-YY)	785	361	154	154	90	439	1,983
Preliminary Screening (PS)	330	0	155	15	0	36	536
Not Earth Orbital (NS)	187	0	240	49	81	137	694
Not Manned Earth Orbital (UM)	0	0	21	23	0	35	79
Covered in Ongoing Programs (OP)	72	0	0	0	14	1	87
Requires Advanced Concepts (AC)	81	2	156	0	122	9	370
Referred to Another Discipline (MS, SB, etc.)	13	0	26	3	8	1	51
Totals	1,468	363	752	244	315	658	3,800

Table 1

MANNED SPACEFLIGHT CAPABILITY CRITICAL ISSUES

1.1 SPACE MEDICINE

1.1.1 BIOMEDICINE

1.1.1.1 Physiological Changes

1.1.1.1.1.1 Cardiac Activity

.1 What changes occur in the electrical activity of the heart, and what are the mechanisms associated with the changes? 1-BM-4

.2 What changes occur in the force of contraction of the heart, and what are the mechanisms associated with the changes? 1-BM-4

.3 What changes occur in the heart sounds, and what is the origin of the changes? 1-BM-4

.4 What changes occur in heart size, and what are the reasons for the change? 1-BM-4

.5 What changes occur in heart rate, and what are the mechanisms associated with the changes? 1-BM-4

1.1.1.1.1.2 Blood Volume

.1 What changes occur in plasma volume, and what are the mechanisms associated with the changes? 1-BM-4

.2 What changes occur in total body water, and what are the mechanisms associated with the changes? 1-BM-4

.3 What changes occur in extracellular fluid volume, and what are the mechanisms associated with the changes? 1-BM-4,-10

.4 What changes occur in RBC mass, and why do the changes occur? 1-BM-4,-10

.5 What changes occur in the amount of blood flow through various areas, and what is the origin of the changes? 1-BM-12

.6 What changes occur in venous pressure, compliance, and stasis, and how are the changes brought about? 1-BM-4,-12

1.1.1.1.1.3 Circulatory Dynamics

.1 What changes occur in cardiac output, and what are the mechanisms associated with the changes? 1-BM-4,-6, -12,-15

.2 What changes occur in circulation time, and what are the mechanisms associated with the changes? 1-BM-4

.3 What changes occur in pulse wave velocity, and what is the significance of the changes? 1-BM-4

.4 What changes occur in arteriolar reactivity, and what mechanisms are associated with the changes? 1-BM-4

.5 What changes occur in blood pressure, and what are the mechanisms associated with the changes? 1-BM-4,-6, -15

1.1.1.1.1.4 Compensatory Reflexes

.1 What changes in normal circulatory compensatory activities are associated with exercise, and how are these changes manifested? 1-BM-6,-14

.2 What changes in normal circulatory compensatory activities are associated with centrifugation ($+G_z$ acceleration)? 1-BM-15

.3 What changes in normal circulatory compensatory activities are associated with the production of lower body negative pressure, and how are the changes manifested? 1-BM-4,-6

.4 What changes in normal circulatory compensatory activities are associated with the use of occlusive pressure cuffs, and how are the changes manifested? 1-BM-4

.5 What changes in normal circulatory compensatory activities are associated with environmental stresses (see 1.3)? 1-BM-6

1.1.1.1.1.5 Blood Gas Transportation

.1 What changes occur in blood gas transportation, and what are the mechanisms associated with the changes? 1-BM-10,-13

1.1.1.1.2.1 Pulmonary Function

.1 What changes occur in vital capacity and its components, and what mechanisms are associated with the changes? 1-BM-13

.2 What changes occur in residual volume, and what mechanisms are associated with the changes? 1-BM-13

.3 What changes occur in dead-space volume, and what mechanisms are associated with the changes? 1-BM-13

.4 What changes occur in inspiratory and expiratory flows and pressures, and what mechanisms are associated with the changes? 1-BM-13

.5 What changes occur in lung compliance, and what mechanisms are associated with the changes? 1-BM-13

.6 What changes occur in normal pulmonary ventilation, and what mechanisms are associated with the changes? 1-BM-13

.7 What changes occur in normal respiratory rate, and what mechanisms are associated with the changes? 1-BM-13

1.1.1.1.2.2 Gas Exchange and Transportation

.1 What changes occur in the alveolar gas contents, and what mechanisms are associated with the changes? 1-BM-13

.2 What changes are associated with arterial and venous oxygen and carbon dioxide tensions, and what mechanisms are associated with the changes? 1-BM-10,-13

.3 What changes are associated with arterial and venous blood pH, and what mechanisms are associated with the changes? 1-BM-10,-13

.4 What changes are associated with the oxygen-carrying capacity of the blood and with hemoglobin saturation (see 1.1.7)? 1-BM-10,-13

1.1.1.1.2.3 Respiratory Control Mechanisms

.1 What changes occur in breath-holding time, and what mechanisms are associated with the changes? 1-BM-13

.2 What changes in normal pulmonary ventilation adjustments are associated with exposure to increased environmental CO_2 levels? 1-BM-6

.3 What changes in normal pulmonary ventilation adjustments are associated with exercise? 1-BM-6,-14

.4 What changes in normal pulmonary ventilation adjustments are associated with exposure to reduced environmental oxygen levels? 1-BM-6

.5 What changes in respiratory compensatory activities are associated with other environmental stresses? 1-BM-6

1.1.1.1.2.4 Ciliary Activity

.1 What changes occur in the ejection of foreign particles from the respiratory tract by ciliary activity? 1-BM-5

.2 What changes occur in the susceptibility to infection due to changes in ciliary activity? SB

1.1.1.1.3.1.1 Otolith Activities

.1 What changes occur in the susceptibility to motion sickness, and what are the mechanisms associated with the changes? 1-BM-7,-15

.2 What changes occur in spatial orientation, and what illusions are associated with the changes? 1-BM-7, -12,-15

.3 What changes occur in sensitivity to linear acceleration, and what are the mechanisms associated with the changes? 1-BM-7, -12,-15

.4 What changes occur in the incidence of oculogravic and oculoagravic illusions associated with exposure to linear accelerations? 1-BM-7,-15

.5 What changes occur in ocular counterrolling, and how are these related to changes in spatial orientation in weightlessness? 1-BM-7

.6 What changes occur in the direction and intensity of Positional Alcoholic Nystagmus (PAN), and what mechanisms are associated with the changes? AC

1.1.1.1.3.1.2 Semicircular Canal Activities

.1 What changes occur in the susceptibility to motion sickness associated with rotation in zero g, and what are the mechanisms associated with the changes? 1-BM-7,-15

.2 What changes occur in sensitivity to angular acceleration, and what are the mechanisms associated with the changes? 1-BM-7,-15

.3 What changes occur in the incidence and intensity of the oculogyral illusion and nystagmus during rotation in weightlessness, and what are the mechanisms associated with the changes? 1-BM-7,-15

.4 What effects do the Coriolis "forces" produced by rotation in zero g have on the precision of limb and body movements? 1-BM-15

.5 What changes occur in spatial orientation during rotation in zero g, and what are the mechanisms associated with the changes? 1-BM-7,-15

1.1.1.1.3.2 Nerve Impulse Transmission

.1 What changes occur in an isolated nerve resting potential, and what are the mechanisms associated with the change? PS

.2 What changes occur in the threshold characteristics of isolated nerve fibers, and what are the mechanisms associated with the changes? PS

.3 What changes occur in the characteristics of nerve impulse transmission in isolated nerve fibers, and what are the mechanisms associated with the changes? PS

.4 What changes occur in the characteristics of nerve impulse transmission at the synapse, and what are the mechanisms associated with the changes? PS

.5 What changes occur in the characteristics of facilitation and inhibition at the synapse, and what are the mechanisms associated with the changes? PS

.6 What changes occur in the chronaxic, and what are the mechanisms associated with the changes? PS

1.1.1.1.3.3 Electroencephalographic Changes

.1 What changes occur in the normal (alpha) rhythms associated with the resting awake state, and how are these differences manifested? 1-BM-7,-12

.2 What changes occur in the mechanisms of "alpha blocking" associated with electroencephalographic arousal, and how are the changes related to objective manifestations of attention? 1-BM-7,-12

.3 What changes occur in the EEG patterns associated with sleep, and how are the changes related to subjective feelings and objective evidence of sleep quality? 1-BM-7,-12

.4 Do any EEG rhythms not included in the subject's normal patterns occur, and can these be related to personality or performance changes? 1-BM-7,-12

1.1.1.1.3.4 Sensory Function

(The analysis of this topic is covered in Behavioral Research - Sensory 1.1.2.1.1.1.)

1.1.1.1.3.5 Motor Performance

(The analysis of this topic is covered in Behavioral Research - Psychomotor 1.1.2.1.1.2.)

1.1.1.1.3.6 Reflex Activity

1.1.1.1.3.6.1 Skeletal Muscle Reflexes

.1 What changes occur in the extensor reflexes, and can the changes be related to changes in general myotatic activity? 1-BM-7

.2 What changes occur in the withdrawal reflexes, and can the changes be related to changes in neural or synaptic transmission? 1-BM-7

.3 What changes occur in reflex responsiveness or reflex spreading, and what mechanisms are associated with the changes? 1-BM-7

.4 What changes occur in reflex inhibition, and what are the mechanisms associated with the changes? 1-BM-7

.5 What changes occur in complex reflex patterns, and what are the mechanisms associated with the changes? 1-BM-7,-12

1.1.1.1.3.6.2 Autonomic Reflexes

.1 What changes occur in circulatory reflexes, and what are the mechanisms associated with the changes? 1-BM-4,-6, -12

.2 What changes occur in visual reflexes, and what are the mechanisms associated with the changes? 1-BM-7

.3 What changes occur in respiratory reflexes, and what are the mechanisms associated with the changes? 1-BM-6, -14

.4 What changes occur in gastrointestinal reflexes, and what are the mechanisms associated with the changes? 1-BM-8

1.1.1.1.3.7 Integrative and Cognitive Processes

(The analysis of this topic is covered in Behavioral Research - Cognitive, 1.1.2.1.1.3.)

1.1.1.1.4.1 Gastrointestinal Motility

.1 What changes occur in the processes of chewing and swallowing, and do the changes interfere with food consumption? 1-LS-6

.2 What changes occur in gastric motility, and to what extent do these changes influence gastric digestion of the foodstuffs? 1-BM-8

.3 What changes occur in gastric emptying time, and to what processes are these changes related? 1-BM-8

.4 What changes occur in the motility of the small intestine, and to what extent will these changes influence digestion of foodstuffs in the small intestine? 1-BM-8

.5 What changes occur in movements of the colon, and what effect do the changes have on fecal formation and defecation? 1-BM-8

.6 Do changes in gastric motility affect the incidence of nausea and the mechanics of vomiting? 1-BM-8

1.1.1.1.4.2 Secretory Processes

.1 What changes occur in salivary secretion, and what effects do the changes have on salivary digestion? 1-BM-8

.2 What changes occur in gastric secretion, and what effects do the changes have on gastric digestion? 1-BM-8

.3 What changes occur in pancreatic secretion, and what effects do the changes have on digestion within the small intestine? 1-BM-8

.4 What changes occur in the secretion of bile, and what effects do the changes have on fat digestion? 1-BM-8

.5 What changes occur in intestinal secretion, and what effects do the changes have on digestion in the small intestine? 1-BM-8

.6 Do changes in gastric secretion produce an increased incidence of hyperacidity and other gastric disturbances? 1-BM-8

1.1.1.1.4.3 Digestive Processes

.1 What changes occur in the digestion of carbohydrates, and what secretory changes are primarily responsible? 1-BM-8

.2 What changes occur in the digestion of fats, and what secretory changes are primarily responsible? 1-BM-8

.3 What changes occur in the digestion of proteins, and what secretory changes are primarily responsible? 1-BM-8

.4 What changes occur in salivary digestion, and what effects do the changes have on the utilization of carbohydrates? 1-BM-8

.5 What changes occur in the general digestion of foodstuffs, and how are these changes related to changes in gastric secretion? 1-BM-8

.6 What changes occur in the general intestinal digestion of foodstuffs, and how are these changes related to changes in pancreatic, bile, and intestinal secretions? 1-BM-8

1.1.1.1.4.4 Gastrointestinal Absorption

.1 What changes occur in absorption of substances from the stomach, and how are these changes related to changes in gastric digestion and empyting? 1-BM-8

.2 What changes occur in the intestinal absorption of water and electrolytes, and what are the mechanisms associated with the changes? 1-BM-8

.3 What changes occur in the absorption of water and electrolytes from the colon, and what are the mechanisms associated with the changes? 1-BM-8

.4 What changes occur in the intestinal absorption of carbohydrates, and what are the mechanisms associated with the changes? 1-BM-8

.5 What changes occur in the intestinal absorption of fats, and what are the mechanisms associated with the changes? 1-BM-8

.6 What changes occur in the intestinal absorption of protein, and what are the mechanisms associated with the changes? 1-BM-8

1.1.1.1.4.5 Biliary and Liver Function

.1 What changes occur in the quantity and composition of the bile secreted by the liver, and what are the mechanisms associated with the changes? AC

.2 What changes occur in the concentration of liver bile by the gall bladder, and what are the mechanisms associated with the changes? AC

.3 What changes occur in the release of bile from the gall bladder into the duodenum, and what are the mechanisms associated with the changes? AC

1.1.1.1.4.6 Gas Formation and Management

.1 What changes occur in the accumulation of gas in the stomach, and are the changes directly related to changes in the amount of swallowed gas? 1-BM-8

.2 What changes occur in the disposition of gas in the stomach, and do the changes result in changes in eructation, borborygmi, or gastric discomfort? 1-BM-8

.3 What changes occur in the amount of gas in the colon, and do the changes result from changes in swallowed gas residue or from a change in gas formed in the colon? 1-BM-8

.4 What changes occur in the disposition of gas in the colon, and do the changes result in a change in the amount and composition of flatus or feelings of abdominal discomfort? 1-BM-8

1.1.1.1.4.7 Fecal Management

.1 What changes occur in the composition and character of the feces, and to what functions are the changes related? 1-BM-8

.2 What changes occur in the volume of the stool and the frequence of defecation, and to what functions are the changes related? 1-BM-8

.3 Do changes in the formation and release of feces necessitate any changes in the design of the waste management system? 1-BM-8

1.1.1.1.4.8 Control of Hunger and Thirst

.1 What changes occur in appetite or hunger, and what are the mechanisms associated with the changes? 1-BM-8

.2 What changes occur in hunger satiation and food intake, and what are the mechanisms associated with the changes? 1-BM-8

.3 What changes occur in food preference, and can preference trends be established among the subjects? 1-BM-8

.4 What changes occur in the ad libitum intake of water, and how are the changes related to normal hydration? 1-BM-8

.5 Do changes that occur in the control of hunger and thirst necessitate changes in the size and frequency of meals and the establishment of a programmed water intake? 1-BM-8

1.1.1.1.5.1 Kidney Function

.1 What changes occur in glomerular filtration, and what are the mechanisms associated with the changes? 1-BM-10

.2 What changes occur in tubular reabsorption, and what are the mechanisms associated with the changes? 1-BM-10

.3 What changes occur in tubular secretion, and what are the mechanisms associated with the changes? 1-BM-10

.4 What changes occur in total renal blood flow, and what are the mechanisms associated with the changes? 1-BM-10

1.1.1.1.5.2 Urine Composition

.1 What changes are evident in a routine urinalysis, and can the changes be related to deleterious effects of prolonged weightlessness? 1-BM-10

.2 What changes occur in the volume, pH, and electrolyte content of the urine, and can the changes be related to changes in the body's fluid and electrolyte balance? 1-BM-10

.3 What changes occur in urine concentration by the kidney during water curtailment, and how do the volume and composition of the concentrated urine compare with that of ground-based studies? 1-BM-10

.4 What changes occur in the volume and composition of urine produced during controlled water diuresis, and how do they compare with diuresis during ground-based studies? 1-BM-10

.5 What changes occur in the volume and composition of urine produced during the administration of an osmotic diuretic, and how do they compare with ground-based experiments? 1-BM-10

.6 What changes occur in body fluid volume, distribution, and electrolyte concentration during urinary concentration and dilution? 1-BM-10

1.1.1.1.5.3 Bladder Control and Micturition

.1 What changes occur in the bladder volume and pressure that initiate voluntary micturition, and what mechanisms are associated with the changes? MS(1-LS-9

.2 What changes occur in the force with which urine is expelled from the uretha, and what mechanisms are associated with the changes? MS(1-LS-9)

.3 Do changes in the frequency, volume, and character of micturition necessitate any changes in the design of the water management system? MS(1-LS-4)

1.1.1.1.5.4 Tissue Hydration

.1 What effects do changes in excretory function have on total body water? 1-BM-10

.2 What effects do changes in excretory function have on extracellular fluid volume? 1-BM-10

.3 What effects do changes in excretory function have on plasma volume? 1-BM-4,-10

.4 What effects do changes in excretory function have on red blood-cell size (diameter)? 1-BM-10

1.1.1.1.5.5 pH of Body Fluids

.1 What effects do changes in excretory function have on the pH of the blood? 1-BM-10

.2 What effects do changes in excretory function have on pH regulation during chronic hypercapnia? AC

.3 What effects do changes in excretory function have on pH during chronic hyperventilation? AC

1.1.1.1.6.1 Intermediary Metabolism

1.1.1.1.6.1.1 Carbohydrate Metabolism

.1 What changes occur in normal blood and urine glucose levels, and how do these vary over a routine 24-hour period? 1-BM-10,-1

.2 What changes occur in the response to glucose tolerance tests, and are the changes more pronounced when glucose is administered orally or intravenously? 1-BM-10,-14

.3 What changes occur in glucose utilization associated with exercise, and what RQ's are associated with the utilization? 1-BM-14

.4 What changes occur in the response to insulin administration, and how are the changes related to liver glycogen stores? AC

.5 What changes occur in the results of golactose tests, and how are the changes related to glycogen production in the liver? 1-BM-10,-14

1.1.1.1.6.1.2 Fat Metabolism

.1 What changes occur in the normal concentration and types of plasma lipids, and how are these changes related to altered lipid metabolism? 1-BM-10,-14

.2 What changes occur in the adipose tissue mass of the crewmen, and what mechanisms are associated with the changes? 1-BM-14

.3 What changes occur in the respiratory quotient and in the development of ketosis during carbohydrate deprivation, and how are these changes related to ground-based experiments? 1-BM-10,-14

1.1.1.1.6.1.3 Protein Metabolism

.1 What changes occur in the results of tests commonly used to reveal malfunction in protein metabolism and associated liver function, such as electrophoresis, flocculation or precipitation tests, albumin-globulin ratios, and serum cholinesterase levels. 1-BM-10,-14

.2 What changes occur in nitrogen balance, and how are the changes related to muscular deconditioning? 1-BM-10,-14

.3 What changes occur in lean body mass, and how are the changes related to muscular deconditioning? 1-BM-14

.4 Do any indications of edema occur with prolonged exposure to weightlessness, and can these be corrected with reductions in plasma protein levels? 1-BM-14

.5 What changes occur in protein metabolism during strenuous exercise, and how are the changes related to normal exercise respiratory quotients? 1-BM-14

1.1.1.1.6.2 Energy Metabolism

.1 What changes occur in the metabolic cost of defined work loads in the categories of moderate, hard, and strenuous work, and to what extent are the changes related to bracing in the tractionless environment? 1-BM-14

.2 What changes occur in the accumulation of oxygen debts associated with defined metabolic loads, and what are the mechanisms associated with the changes? 1-BM-6, -10,-14

.3 What changes occur in the maximal oxygen consumption in weightlessness, and to what extent do the changes limit spacecraft work loads? 1-BM-14

.4 What changes occur in standard physical fitness measurements, and how are the changes related to muscular deconditioning? 1-BM-14

1.1.1.1.6.3 Muscle Size and Strength

.1 What changes occur in dynomometer measurements of various muscles, and what is the relationship of the changes to changes in protein metabolism? 1-BM-14

.2 What changes occur in muscle size in various areas of the body, and what is the relationship of the changes to changes in protein metabolism? 1-BM-14

.3 What changes occur in the electromyogram of muscles, both at rest and during measured contractions? 1-BM-14

1.1.1.1.6.4 Calcium and Phosphorous Metabolism

.1 What changes occur in the blood and urine levels of calcium and phosphorus, and serum alkaline phosphatase, and what are the mechanisms associated with the changes? 1-BM-10,-14

.2 What changes occur in the density of various bones, and how does each correlate with the overall changes in the density of the skeletal system? 1-BM-14

.3 Do stresses such as exercise or centrifugation alter the changes in calcium-phosphorus metabolism and bone density? 1-BM-10, -14,-15

.4 Do changes in dietary calcium alter changes in calcium metabolism, and what is the relationship to bone density changes? 1-BM-10,-1

1.1.1.1.6.5 Metabolic Balance

.1 What changes occur in metabolic balance, and can the changes be attributed to specific changes in intermediary metabolism? 1-BM-10,-1

.2 Can changes in dietary components alter changes in metabolic balance, and how do the changes affect space-flight nutritional requirements? 1-BM-8,-14

1.1.1.1.7.1 Element Morphology

.1 What changes occur in the size, color, shape, and volume of the erythrocytes, and what are the mechanisms associated with the changes? 1-BM-10

.2 What changes occur in the percentage of juvenile cells, and what are the mechanisms associated with the changes? 1-BM-10

.3 What changes occur in the total number and percentage of types of leukocytes, and what are the mechanisms associated with the changes? 1-BM-10

.4 What changes occur in blood platelet count, and what are the mechanisms associated with the changes? 1-BM-10

1.1.1.1.7.2 Element Dynamics

.1 What changes occur in erythrocyte fragility, and what are the mechanisms associated with the changes? 1-BM-4,-10

.2 What change occur in the erythrocyte production rate, and what are the mechanisms associated with the changes? 1-BM-4,-10

.3 What changes occur in the erythrocyte life span, and what are the mechanisms associated with the changes? 1-BM-4,-10

.4 What changes occur in the hemoglobin content and oxygen-combining capacity of the blood, and what mechanisms are associated with the changes? 1-BM-10,-1

.5 What changes occur in the motility and phagocytic activity of the leukocytes, and what are the mechanisms associated with the changes? 1-BM-10

1.1.1.1.7.3 Blood Clotting and Hemostasis

.1 What changes occur in clot formation in the blood, what are the mechanisms for the changes, and what is the effect on clotting time? 1-BM-10

.2 What changes occur in clot retraction, what are the mechanisms associated with the changes, and what is the effect on bleeding time? 1-BM-10

.3 What changes occur in the fibrinolytic activity of the blood, what are the mechanisms associated with the changes, and what is the effect on intravascular clotting (thrombosis)? 1-BM-10

1.1.1.1.7.4 Plasma Proteins

.1 What changes occur in the total plasma albumine and globulin and the A-G ratio, and what effect do the changes have on plasma osmolarity? 1-BM-10

.2 What changes occur in plasma protein formation, and how are the changes related to protein metabolism and liver function? 1-BM-10

.3 What changes occur in plasma fibrinogen, and what is the effect on the clotting mechanisms? 1-BM-10

.4 What changes occur in the percentages of the various globulin fractions, and how will changes in α globulin affect antibody formation? 1-BM-10

.5 What changes occur in serum electrolytes, and what are the mechanisms associated with the changes? 1-BM-10

1.1.1.1.7.5 Immunological Changes

.1 What changes occur in the amount and type of serum immune components? SB

.2 What changes occur in immune reactions to a microbiological challenge? SB

1.1.1.1.8.1 Hormone Synthesis and Release

.1 What changes occur in the normal blood levels of the various hormones, and how are the changes related to changes in hormone-controlled functions? 1-BM-10

.2 What changes occur in the chemical structure of the hormones synthesized by the various endocrine glands, and what effects will result in hormone activity in bioassay studies? 1-BM-10

1.1.1.1.8.2 Effects on Target Tissues

.1 What changes occur in the effects of the various stimulating hormones released by the pituitary gland on the various target endocrine glands? SB

.2 What changes do the administration of calibrated amounts of various hormones have on the activities of the normal target organs and tissues of the hormones? SB

1.1.1.1.8.3 Endocrine Regulation

.1 What changes occur in the normal levels and activity of endocrine-stimulating hormones released by the pituitary? AC

.2 What changes occur in the normal alteration and release of stimulating hormones by the pituitary gland with hormone administration? AC

.3 What changes occur in the release of hormones by the various endocrine glands with varying blood levels of stimulating hormones? AC

.4 What changes occur in the normal feedback relationship between endocrine activity and the blood levels of control substances other than pituitary hormones? 1-BM-10

1.1.1.1.9 Reproductive Function

Note—It is not supposed that experiments in this area will be included in currently considered space programs.

.1 What changes occur in spermatogensis, oogenesis, and ovulatory function, and what are the mechanisms associated with the changes? PS

.2 What changes take place in the process of copulation and fertilization and what are the reasons for the changes? PS

.3 What changes take place in fetal development and what are the mechanisms associated with the changes? PS

.4 What changes occur in the process of parturition and what are the mechanisms associated with the changes? PS

1.1.1.2.1.1 Routes of Drug Administration

.1 Do changes in dermal metabolism or skin blood flow produce any changes of absorption in topically administered drugs? AC

.2 Do changes in gastrointestinal activity produce any changes in the absorption or orally administered drugs? AC

.3 Do changes in circulatory activity or body fluid balance produce any changes in the effectiveness of systemically administered drugs, including intravenous, intramuscular, intraperitoneal, intradural, and subcutaneous routes of administration? AC

.4 Do changes in respiratory function produce any changes in the absorption of drugs administered by inhalation? AC

1.1.1.2.1.2 Drug Action

.1 Do any changes occur in the dose-effect relationship of drugs, and what is the nature of the changes? AC

.2 Do any changes occur in the site of action or selectivity of drugs, and what is the nature of the changes? AC

.3 Do any changes occur in the duration of drug action, and what is the nature of the changes? AC

.4 Do any changes occur in the metabolic fate of drugs, and what is the nature of the changes? AC

.5 Do any changes occur in the renal elimination of drugs, and what is the nature of the changes? AC

.6 Do any changes occur in the toxicity and side effects of drugs, and what is the nature of the changes? AC

.7 Do any changes occur in the interactions or idiosyncrasies of drugs, and what is the nature of the changes? AC

NOTE: Each of the seven questions under 1.1.1.2.1.2 should be applied to at least one member of each of the general classes of drugs. If changes are found, additional members of the class may be investigated. Examples of general drug classes are as follows:

a. Drugs that affect muscle tissue
   1. Cardiac muscle stimulants
   2. Cardiac muscle depressants
   3. Skeletal muscle stimulants
   4. Skeletal muscle depressants

b. Drugs that affect blood
   1. Hematinics
   2. Anticoagulants
   3. Hemostatics
   4. Plasma volume expanders

c. Drugs that affect blood vessels
   1. Coronary vasodilators
   2. Systemic vasodilators
   3. Systemic vasoconstrictors

d. Drugs that affect the central nervous system
   1. Analgesics
   2. Counterirritants
   3. Sedatives
   4. Hypnotics
   5. Tranquilizers
   6. Psychomotor stimulants
   7. Psychotomimetics
   8. Anticonvulsants
   9. Anesthetics
   10. Antimotion sickness drugs

e. Drugs that affect the autonomic nervous system
   1. Cholinergic agents
   2. Cholinergic inhibitors
   3. Cholinergic blocking agents
   4. Adrenergic agents
   5. Adrenergic blocking agents

f. Drugs that affect vision
   1. Pupillary dilators and constrictors
   2. Drugs affecting visual accommodation

g. Drugs that affect the liver and gall bladder
   1. Choleretics
   2. Chologogues

h. Drugs that affect gastrointestinal function
   1. Antacids
   2. Emetics
   3. Antiemetics
   4. Catharits
   5. Carminatives

i. Drugs used as chemotherapeutic agents

j. Drugs replacing or mimicking a functional product of the body
   1. Enzymes
   2. Hormones
   3. Vitamins

k. Miscellaneous drugs
   1. Antipyretics
   2. Expectorants
   3. Antihistamines

1.1.1.2.2 Microbial Infections

.1 What changes occur in the number of types of microbial forms contaminating spacecraft surfaces? SB

.2 What changes occur in the number and types of microbial forms contaminating the spacecraft atmosphere? SB

.3 What changes occur in the number and types of microbial forms revealed by a microbial evaluation of crew members? SB

.4 Do changes in respiratory function cause the crew members to become more susceptible to microbial infection? SB

.5 Are changes produced in the normal characteristics and properties of microbial forms during prolonged exposure to weightlessness? SB

.6 Are changes in sanitary procedures necessitated by changes in microbial activities during prolonged weightlessness? SB

1.1.1.2.3 Traumatic Injuries

.1 What changes occur in the healing rates for lacerations, contusions, and abrasions, and what mechanisms are associated with the changes? 1-BM-5

.2 What changes occur in the healing rates for burns, and what mechanisms are associated with the changes? 1-BM-5

.3 What change occur in the rates for fracture healing, and what mechanisms are associated with the changes? 1-BM-5

.4 What changes occur in the healing rates of cold injury, and what mechanisms are associated with the changes? AC

.5 What changes occur in the healing rates of lung trauma and related decompression-induced injuries, and what are the mechanisms associated with the changes? AC

.6 What changes occur in the healing and recovery rates of eye injuries and foreign body problems, and what are the mechanisms associated with the changes? AC

.7 Will the changes that occur in the healing process following noninfectious traumatic injuries necessitate any revisions in the treatment of the injury or the disposition of the injured crewman? 1-BM-5

1.1.1.2.4 Diagnostic Signs

.1 Can any of the changes observed to occur in relation to physiological deteriorations produced by prolonged exposure to zero g be used as a trustworthy indicator of the onset of the deterioration? 1-BM-12

.2 Can the variables normally measured in a routine physical examination still be used as indicators of the general health of the subject after prolonged exposure to zero-g? 1-BM-4, -7,-13

1.1.1.2.5.1 Artificial Gravity

.1 What is the magnitude of artificial gravity required to prevent the occurrence of deleterious biomedical changes? AC

.2 How much time per day must be spent in an artificial gravity environment to prevent the occurrence of deleterious biomedical changes? AC

1.1.1.2.5.2 Exercise

.1 What form of exercise is best suited to the prevention of the occurrence of deleterious biomedical changes? 1-BM-6

.2 How much time per day must be spent on the exercise program to prevent the occurrence of deleterious biomedical changes? 1-BM-6

1.1.1.2.5.3 Centrifugation

.1 What centrifugation profile is most effective in preventing the occurrence of deleterious biomedical changes? 1-BM-15

.2 How much time per day must be spent in centrifugation to prevent the occurrence of deleterious biomedical changes? 1-BM-15

1.1.1.2.5.4 Redistribution of Blood Volume 1-BM-6

.1 Can a periodic redistribution of blood volume by devices, such as the lower body negative pressure device and occlusive garments or cuffs, or by increasing intrathoracic pressure, be used to prevent cardiovascular deconditioning?

1.1.1.2.5.5 Drug Administration AC

.1 Can the administration of drugs or chemicals prevent the occurrence of deleterious biomedical changes?

1.1.1.2.5.6 Stress Acclimatization

.1 Can adaptation to a reduced oxygen pressure (hypoxia) in the spacecraft atmosphere prevent the occurrence of deleterious biomedical changes? AC

.2 Can adaptation to a high temperature (hyperthermia) in the spacecraft environment prevent the occurrence of deleterious biomedical changes? AC

.3 Can adaptation to a high carbon dioxide pressure (hypercapnia) in the spacecraft atmosphere prevent the occurrence of deleterious biomedical changes? AC

1.1.1.2.5.7 Reversal of Change 1-BM-6

.1 Can any of the measures found effective in preventing the occurrence of deleterious biomedical changes be used to reverse the biomedical change if it has already occurred?

1.1.1.3.1.1 Neurological Effects

.1 What changes occur in the effects of hypoxia on the time of useful consciousness (TUC), and what are the mechanisms associated with the changes? 1-BM-6

.2 What changes occur in the effects of hypoxia on vision, and what are the mechanisms associated with the changes? 1-BM-6

.3 What changes occur in the effects of hypoxia on the electroencephalogram, and what are the mechanisms associated with the changes? 1-BM-6

1.1.1.3.1.2 Cardiovascular Effects

.1 What changes occur in cardiac response to hypoxia and what mechanisms are associated with the changes? 1-BM-6

.2 What changes occur in the vascular response to hypoxia, and what mechanisms are associated with the changes? 1-BM-6

.3 What changes occur in the effects of hypoxia on the electrocardiogram, and what are the mechanisms associated with the changes? 1-BM-6

1.1.1.3.1.3 Respiratory Effects

.1 What changes occur in the ventilatory response to hypoxia, and what are the mechanisms associated with the changes? 1-BM-6

.2 What changes occur in the effects of hypoxia on blood oxygenation, and what are the mechanisms associated with the changes? 1-BM-6

.3 What changes occur in the effects of hypoxia on respiratory alkalosis, and what are the mechanisms associated with the changes? AC

1.1.1.3.1.4 Hematological Characteristics

.1 What changes occur in the effects of hypoxia on hemoglobin oxygen saturation, and what are the mechanisms associated with the changes? AC

.2 What changes occur in the effects of hypoxia on blood pH and blood bicarbonates, and what are the mechanisms associated with the changes? AC

1.1.1.3.1.5 Other Effects

.1 What changes occur in the endocrine response to hypoxia, and what are the mechanisms associated with the changes? AC

.2 What changes in response and tolerance to hypoxia during prolonged weightlessness result in any modification in the normal and emergency limits for oxygen concentrations in the spacecraft atmosphere? 1-BM-6

1.1.1.3.2 Tolerance to Increased CO_2

.1 What changes occur in the ventilatory response to elevated atmosphereic CO_2, and how do the changes affect the alveolar CO_2 levels? 1-BM-6

.2 What changes occur in the cardiovascular response to elevated atmospheric CO_2, and how is the response affect the alveolar CO_2 levels. 1-BM-6

.3 What variations occur in blood pH and bicarbonate levels, and are the changes related to changes in the blood buffering mechanisms? 1-BM-6

.4 What changes in response and tolerance to carbon dioxide during prolonged weightlessness result in a revision of the normal and emergency limits imposed on carbon dioxide concentrations in the spacecraft atmosphere? 1-BM-6

1.1.1.3.3 Tolerance to Diluent Gas Effects

.1 What effect do changes in the type and pressure of diluent gas have on the mechanics of breathing and the distribution of inspired gas? (All candidate diluent gases would be examined.) AC

.2 What effect does prolonged exposure to a diluent gas have on the susceptibility to Grade II bends during subsequent exposure to reduced pressures? (All candidate diluent gases would be examined.) AC

.3 What effect do changes in the type and pressure of diluent gas have on temperature control, and are changes in temperature control fully explained by differences in thermal conductivity of the diluent gas? AC

.4 Do changes in the effects of various diluent gases during prolonged weightlessness result in revised recommendations concerning the type and pressure of diluent gases in the spacecraft atmosphere? AC

1.1.1.3.4 Acceleration Tolerance

.1 What changes occur in grayout and blackout thresholds with exposure to acceleration in various directions related to mission profiles? 1-BM-15

.2 What changes occur in cardiovascular responses to acceleration exposures, and how are these related to cardiovascular deconditioning? 1-BM-15

.3 What changes occur in tidal volumes, respiratory rates, respiratory dead spaces, and maximum breathing capacities with exposure to accelerations, particularly those related to mission profiles? 1-BM-15

.4 Do changes in response and tolerance to acceleration necessitate any revisions in the acceptable acceleration limits normally imposed on the mission profile? 1-BM-15

1.1.1.3.5.1 Elevated Temperatures

.1 What changes occur in the time required to reach physiological limits in core temperature and average body temperature with exposure to elevated environmental temperatures, and which of the measured sites shows the greatest change? 1-BM-6

.2 What changes occur in the cardiovascular response to elevated environmental temperatures, and what are the mechanisms associated with the changes? 1-BM-6

.3 What changes occur in respiratory rate, ventilation rate, and the composition of alveolar air associated with exposure to elevated environmental temperatures, and what are the mechanisms associated with the changes? 1-BM-6

.4 What changes occur in the normal sweating response to elevated environmental temperatures, and of what significance are the changes in temperature regulation? 1-BM-6

1.1.1.3.5.2 Depressed Temperatures

.1 What changes occur in the time required to reach physiological limits in core temperature and average body temperature with exposure to depressed environmental temperatures, and which of the measured body sites shows the greatest change? AC

.2 What changes occur in the cardiovascular response to depressed environmental temperatures, and what are the mechanisms associated with the changes? AC

.3 What changes occur in the metabolic response to depressed environmental temperatures, and what is the significance of the change in body temperature control? AC

.4 What changes occur in the core temperature at which shivering begins, and what changes are produced in the metabolic rates associated with shivering? AC

.5 What changes occur in the endocrine response to depressed environmental temperatures, and what are the mechanisms associated with the changes? AC

.6 Do changes in response and tolerance to environmental temperature variations during prolonged weightlessness result in any modifications in the normal temperature and thermal limits recommended for the spacecraft environment? AC

1.1.1.3.6 Exercise Tolerance

.1 What changes occur in the oxygen consumption and metabolic rates associated with various work loads, and what are the mechanisms associated with the changes? 1-BM-6,-14

.2 What changes occur in the cardiovascular response to strenuous work, and what are the mechanisms associated with the changes? 1-BM-6,-14

.3 What changes occur in the ventilatory response to strenuous work, and what changes occur in the composition of alveolar gases? 1-BM-6,-14

.4 What changes occur in maximal oxygen consumption, and what are the mechanisms associated with the changes? 1-BM-6,-14

.5 What changes occur in the oxygen debt associated with various work loads, and what is the significance of the change in exercise tolerance? 1-BM-6,-14

.6 What changes occur in body temperature regulation during exercise, and what are the mechanisms associated with the changes? 1-BM-6,-14

.7 Do changes in response and tolerance to strenuous exercise during prolonged weightlessness result in any modifications to work load limitations imposed on the spacecraft crew? 1-BM-6,-14

1.1.1.3.7 Radiation Tolerance

.1 What changes occur in the LD50 of experimental animals exposed to a standard radiation source, and what mechanisms are associated with the changes? 1-BM-5

.2 What changes occur in the radiation dose required to produce symptoms of radiation sickness in experimental animals subjected to acute whole-body exposure? 1-BM-5

.3 What changes occur in the radiation dose necessary to produce hematological effects in experimental animals, and how do the effects compare with those produced in ground-based experiments? 1-BM-5

.4 What changes occur in the radiation dose necessary to produce dermal effects in experimental animals, and how do the effects compare with those produced in ground-based experiments? 1-BM-5

.5 Do changes in tolerance to radiation in experimental animals during prolonged weightlessness result in any revision of radiation limits in the spacecraft environment? 1-BM-5

1.1.1.3.8 Tolerance to Toxic Contaminants

.1 What changes occur in the LD50 and LC50 of various compounds for experimental animals during prolonged weightlessness, and what is the mechanism responsible for the change? 1-BM-5

.2 What changes occur in the normally anticipated symptoms in experimental animals exposed to various levels of toxic contaminants, and what are the mechanisms responsible for the changes? 1-BM-5

.3 Do changes in tolerance to toxic contaminants in experimental animals exposed to prolonged weightlessness result in any revision of Threshold Limit Values (TLV) established from ground-based experiments? 1-BM-5

1.1.2 MAN–SYSTEMS INTEGRATION

1.1.2.1 Behavioral Research

1.1.2.1.1 Individual Behavioral Research

1.1.2.1.1.1 Sensory

1.1.2.1.1.1.1 Auditory

.1	Do changes occur in long-term spaceflight in threshold tolerance for detection of intensity and frequency of auditory stimuli?	1-BR-1-2
.2	What is the cause of any changes observed?	NS
.3	What is the course of changes observed?	1-BR-1-2
.4	Are there significant differences between individuals in observed changes?	1-BR-1-2
.5	Can effects of observed changes be ameliorated by design, training, or procedural changes?	NS
.6	What physiological measurements are correlated with changes in auditory thresholds?	1-BR-1-2
.7	Can effects of observed changes be prevented by changes in frequency or intensity of auditory stimulus?	NS
.8	Do changes occur in long-term spaceflight in ability to detect changes in tone patterns?	1-BR-1-2
.9	What is the cause of any changes observed?	NS
.10	What is the course of change over time of any observed changes ?	1-BR-1-2
.11	What are the individual differences in observed changes?	1-BR-1-2
.12	Can changes be prevented by training?	NS
.13	Can effects of observed changes be ameliorated by design or procedural changes?	NS
.14	Are there any physiological correlates of observed changes?	1-BR-1-2
.15	Do changes occur in long-term spaceflight in ability to locate the source of sounds?	1-BR-1-2
.16	What is the cause of any changes observed?	NS

.17	What is the course of change over time of any changes observed?	1-BR-1-2
.18	What are the individual differences in observed changes?	1-BR-1-2
.19	Can changes be prevented by training?	NS
.20	Can effects of observed changes be ameliorated by design or procedures changes?	NS
.21	Are there any physiological correlates of observed changes?	1-BR-1-2
.22	Do changes occur in long-term spaceflight in ability to detect direction of movement of a moving auditory stimulus?	1-BR-1-2
.23	What is the cause of any changes observed?	NS
.24	What is the course of change over time of any observed changes?	1-BR-1-2
.25	Are there significant differences between individuals in observed changes?	1-BR-1-2
.26	Can changes be prevented by training?	NS
.27	Can effects of changes be ameliorated by design or procedural changes?	NS
.28	Are there any physiological correlates of observed changes?	1-BR-1-2
.29	Do changes occur in long-term spaceflight in ability to detect duration of auditory tones presented at just above threshold?	1-BR-1-2
.30	What is the cause of any changes observed?	NS
.31	What is the course of change over time of any observed changes?	1-BR-1-2
.32	What are the individual differences in observed changes?	1-BR-1-2
.33	Can changes be prevented by training?	NS
.34	Can effects of changes be ameliorated by design or procedures changes?	NS
.35	What are the physiological correlates of observed changes?	1-BR-1-2

.36 To which typical mission tasks are the various auditory abilities related? PS

.37 During which portions of typical space missions is performance of auditory function required? PS

.38 How can sensing and measuring of auditory abilities be automated or mechanized? NS

1.1.2.1.1.1.2 Somesthetic

.1 Do changes occur in long-term spaceflight in ability to detect differences in pressure on body extremities? PS

.2 What is the cause of any changes observed? PS

.3 What is the course of change over time of any observed changes? PS

.4 Are there significant differences between individuals in observed changes? PS

.5 Can changes be prevented by training. PS

.6 Can effects of observed changes be ameliorated by design or procedures changes? PS

.7 Are there any physiological correlates of observed changes? PS

.8 To which typical mission tasks is the ability to detect and discriminate force against body extremities related? PS

.9 During which phases of a typical space mission is performance of this function required? PS

.10 How can sensing and measuring of changes in this function be mechanized? PS

.11 Do changes in sterognosis occur in long-term spaceflight (ability to discriminate the form and distinctive characteristics of objects by touch alone)? PS

.12 What is the cause of any changes observed? PS

.13 What is the course of change over time of any observed changes? PS

.14 Are there any significant differences between individuals in observed changes? PS

.15 Can changes be prevented by training? PS

.16 Can effects of observed changes be ameliorated by design or procedures changes? PS

.17 What are the physiological correlates of observed changes? PS

.18 To which typical mission tasks is this function related? PS

.19 During which portions of a typical space mission is performance of this function required? PS

.20 How can sensing and measuring of changes in this function be mechanized? PS

.21 Do changes in threshold for detection of vibration occur in long-term spaceflight? PS

.22 What is the cause of any change observed? PS

.23 What is the course of change over time of any observed changes? PS

.24 What are the individual differences in observed changes? PS

.25 Can changes be prevented by training? PS

.26 Can effects of observed changes be ameliorated by design or procedures changes? PS

.27 Are there any physiological correlates of observed changes? PS

.28 To which typical mission tasks is this function related? PS

.29 During which portions of a typical space mission is performance of this function required? PS

.30 How can sensing and measuring of changes in this function be mechanized? PS

.31 Do changes in threshold for detection of light touch occur in long-duration spaceflight? PS

.32 What is the cause of any changes observed? PS

.33 What is the course of change over time of any observed changes? PS

.34 Are there significant differences between individuals in observed changes? PS

.35 Can changes be prevented by training? PS

.36 Can effects of observed changes be ameliorated by design or procedures changes? PS

.37 What are the physiological correlates of observed changes? PS

.38 To which typical mission tasks is this function related? PS

.39 During which portions of a typical space mission is performance of this function required? PS

.40 How can sensing and measuring of changes in this function be mechanized? PS

.41 Do pain thresholds change in long-duration spaceflight? PS

.42 What is the cuase of any changes observed? PS

.43 What is the course of change over time of any observed changes? PS

.44 Are there significant differences between individuals in observed changes? PS

.45 Can changes be prevented by training? PS

.46 Can effects of observed changes be ameliorated by design or procedures changes? PS

.47 What are the physiological correlates of observed changes? PS

.48 How is degradation in this function related to space success? PS

.49 How can sensing and measuring of changes in this function be mechanized? PS

.50 Do changes in threshold for detection of temperature differences occur in long-term space flight? PS

.51 What is the cause of any changes observed? PS

.52 What is the course of change over time of any observed changes? PS

.53 Are there significant differences between individuals in observed changes? PS

.54 Can changes be prevented by training? PS

.55 Can effects of observed changes be alleviated pharmacologically or by procedures changes? PS

.56 Are there any physiological correlates of observed changes? PS

.57 How are changes in this function related to space mission success? PS

.58 How can sensing and measuring of this function be mechanized? PS

.59 Do changes occur during long-duration spaceflight in the ability to discriminate objects by touch using only surface texture cues? PS

.60 What is the cause of any changes observed? PS

.61 What is the course of change over time of any observed changes? PS

.62 What are the individual differences in observed changes? PS

.63 Can changes be prevented by training? PS

.64 Can effects of observed changes be ameliorated by design or procedures changes? PS

.65 What are the physiological correlates of observed changes? PS

.66 To which typical space mission tasks is this function related? PS

.67 During which portion of a typical space mission is performance of this function required? PS

.68 How can sensing and measuring of this function be mechanized? PS

1.1.2.1.1.1.3 Visual

.1 Do changes in visual acuity occur in long-duration spaceflight? 1-BR-1-1

.2 What is the cause of any changes observed? NS

.3 What is the course of change over time of any observed changes? 1-BR-1-1

.4 Are there significant differences between individuals in observed changes? 1 BR-1-1

.5 Can observed changes be prevented or ameliorated by design, training, or procedures changes? NS

.6 What physiological measurements are correlated with changes in visual acuity? 1-BR-1-1

.7 Can effects of observed changes be prevented by changes in ambient lighting? NS

.8 To which typical mission tasks is visual acuity related? PS

.9 During which portions of typical space missions is performance of visual acuity function required? PS

.10 How can sensing and measuring of visual acuity changes be automated or mechanized? NS

.11 What is the effect on visual acuity of the extreme contrasts of light found in space? AC

.12 How do different types of spacecraft cabin and instrument lighting affect visual acuity? NS

.13 How is visual acuity affected by spacecraft dynamics (acceleration, rotation, vibration)? 1-BR-1-1

.14 How effective are optical aids in enhancing visual acuity in long-duration spaceflight? 1-MM-5

.15 How is visual acuity affected by protective and filtering devices? 1-MM-5

.16 What is the effect of unusual gaseous environments on visual acuity? NS

.17 Do changes occur in long-duration space flight inability to perceive relative distances of objects at both close and far range? 1-BR-1-1

.18 What is the cuase of any changes observed? NS

.19 What is the course of change over time of any observed changes? 1-BR-1-1

.20 Are there significant differences between individuals in observed changes? 1-BR-1-1

.21 Can observed changes be prevented or ameliorated by design, training, or procedures changes? NS

.22 What physiological measurements are correlated with changes in depth perception? 1-BR-1-1

.23 To which typical mission tasks is depth perception related? PS

.24 During which portions of typical space missions is performance of depth perception function required? PS

.25 How can sensing and measuring of depth perception changes be automated or mechanized? NS

.26 How does the provision of partial gravity affect depth perception? 1-BR-1-1

.27 How can periodic practice improve depth perception? NS

.28 What cues can be provided to facilitate depth perception in long term spaceflight. NS

.29 What is the effect on depth perception of the extreme contrasts found in space? AC

.30 How is depth perception affected by spacecraft dynamics (acceleration, vibration, rotation)? 1-BR-1-1

.31 How is depth perception affected by protective and filtering devices? 1-MM-5

.32 How do target features such as reflectivity, relative motion, distance, and size affect capability for depth perception? AC

.33 How effective is on-orbit learning in overcoming the effects of spaceflight on depth perception? NS

.34 What is the effect of brightness and color on depth perception in space? AC

.35 Do changes occur in long duration spaceflight in ability to perceive objects in the peripheral portion of the visual field? 1-BR-1-1

.36 What is the cause of any changes observed? NS

.37 What is the course of change over time of any observed changes? 1-BR-1-1

.38 Are there significant differences between individuals in observed changes? 1-BR-1-1

.39 Can observed changes be prevented or ameliorated by design, training, or procedures changes? NS

.40 What physiological measurements are correlated with changes in peripheral vision? 1-BR-1-1

.41 To which typical mission tasks is peripheral vision related? PS

.42 During which portions of typical space missions is performance of peripheral vision function required? PS

.43 How can sensing and measuring of peripheral vision be automated or mechanized? NS

.44 How is peripheral vision affected by protective and filtering devices? 1-MM-5

.45 What is the effect of brightness and color on peripheral vision in space? 1-BR-1-1

.46 Do changes in ability to detect differences in brightness occur in long duration spaceflight? 1-BR-1-1

.47 What is the cause of any observed changes? NS

.48 What is the course of change over time of any observed changes? 1-BR-1-1

.49 Are there significant differences between individuals in observed changes? 1-BR-1-1

.50 Can observed changes be prevented or ameliorated by design, training, or procedures changes? NS

.51 Do changes occur in long duration spaceflight in ability to identify complex visual patterns in terms of time required, errors in identification, and sensitivity? 1-BR-1-1

.52 What is the cause of any observed changes? NS

.53 What is the course of change over time of any observed changes? 1-BR-1-1

.54 Are there significant differences between individuals in observed changes? 1-BR-1-1

.55 Can observed changes be prevented or ameliorated by design, training, practice, performance aids, or procedures changes? NS

.56 What physiological measurements are correlated with changes in this function. 1-BR-1-1

.57 To which typical mission tasks is this function related? PS

.58 During which portions of typical space missions is performance of this function required? PS

.59 How can sensing and measuring of this function be automated or mechanized? NS

.60 How is performance of this function affected by protective and filtering devices? 1-MM-5

.61 What is the effect of various cues (such as position, brightness, color, shape) on ability to perform this function. 1-BR-1-1

.62 Do changes occur in long-duration spaceflight in ability to detect differences in color hue, saturation, and brightness? 1-BR-1-1

.63 What is the cause of any changes observed? NS

.64 What is the course of change over time? 1-BR-1-1

.65 Are there significant differences between individuals in observed changes? 1-BR-1-1

.66 What physiological measurements are correlated with changes in this function? 1-BR-1-1

.67 Can observed changes be prevented or ameliorated by training, design, performance aids, or procedures changes? NS

.68 To which typical mission tasks is performance of this function related? PS

.69 During which portions of a typical space mission is performance of this function required? PS

.70 How is performance of this function affected by S/C dynamics (acceleration, rotation, vibration)? 1-BR-1-1

.71 How can sensing and measuring of changes in this function be automated or mechanized? NS

.72 Do changes occur in long-duration spaceflight in ability to focus on far objects after long periods of focusing on near objects? 1-BR-1-1

.73 What is the cause of any changes observed? NS

.74 What is the course of change over time? 1-BR-1-1

.75 Are there significant differences between individuals in observed changes? 1-BR-1-1

.76 What physiological measurements are correlated with changes in this function? 1-BR-1-1

.77 How can observed changes be prevented or ameliorated? NS

.78 How can sensing and measuring of this function be automated or mechanized? NS

.79 Do changes occur in dark adaptation capabilities in long-duration spaceflight? 1-BR-1-1

.80 What is the cause of any observed changes? NS

.81 What is the course of change over time? 1-BR-1-1

.82 Are there significant differences between individuals in observed changes? 1-BR-1-1

.83 What physiological measurements are correlated with changes in this function? 1-BR-1-1

.84 How can observed changes be prevented or ameliorated? NS

1.1.2.1.1.1.4 Orientation

1.1.2.1.1.1.4.1 Motion Sensing

.1 Do changes occur in long-term spaceflight in ability to detect rotation of the whole body (time from onset to detection; degrees of rotation before detection)? 1-BR-1-5

.2 What is the cause of any changes observed? NS

.3 What is the course of change over time? 1-BR-1-5

.4 Are there significant differences between individuals in observed changes? 1-BR-1-5

.5 What physiological measurements are correlated with observed changes? 1-BR-1-5

.6 Can observed changes be prevented or ameliorated by training, practice, design, performance aids, or procedures changes? NS

.7 How can changes in this function be predicted? NS

.8 To which typical mission tasks is this function related? PS

.9 During which portions of typical missions is performance of this function required? PS

.10 How is performance of this function affected by spacecraft dynamics (acceleration, rotation, and vibration)? 1-BR-1-5

.11 How is performance of this function affected by rate of acceleration, rate changes, and presence or absence of visual cues? 1-BR-1-5

.12 Do changes occur in long-term spaceflight in ability to detect linear movement of the whole body (time from onset to detection; distance traveled before detection)? 1-BR-1-5

.13 What is the cause of any changes observed? NS

.14 What is the course of change over time? 1-BR-1-5

.15 Are there significant differences between individuals? 1-BR-1-5

.16 What physiological measurements are correlated with observed changes? 1-BR-1-5

.17 Can observed changes be prevented or ameliorated by training, practice, design, performance aids, or procedures changes? NS

.18 Can changes in this function be predicted? NS

.19 To which typical space mission tasks is this function related? PS

.20 During which portions of typical space missions is performance of this function required? PS

.21 How is performance of this function affected by spacecraft dynamics (acceleration, rotation, and vibration)? 1-BR-1-5

.22 How is performance of this function affected by speed of motion, rate of onset, rate of change in velocity, and presence or absence of visual cues? 1-BR-1-5

.23 Do changes occur in long-term spaceflight in ability to detect movement of body members? 1-BR-1-5

.24 What is the cause of any observed changes? NS

.25 What is the course of change over time? 1-BR-1-5

.26 Are there significant differences between individuals in observed changes? 1-BR-1-5

.27 What physiological measurements are correlated with observed changes? 1-BR-1-

.28 Can observed changes be prevented or ameliorated by training, practice, design, performance aids, or procedures changes? NS

.29 Can changes in this function be predicted? NS

.30 To which typical space-mission tasks is performance of this function related? PS

.31 During which portions of typical space missions is performance of this function required? PS

.32 How is performance of this function affected by spacecraft dynamics (acceleration, rotation, vibration)? 1-BR-1-

.33 How is performance of this function affected by absence of visual cues, speed of movement, rate of onset, and rate of change in velocity? 1-BR-1-

1.1.2.1.1.1.4.2 Position Sensing

.1 Do changes occur in long-duration spaceflight in ability to identify location of extremities? 1-BR-1-

.2 What is the cause of any observed changes? NS

.3 What is the course of change over time? 1-BR-1-

.4 Are there significant differences between individuals in observed changes? 1-BR-1-

.5 What physiological measurements are correlated with observed changes? 1-BR-1-

.6 Can observed changes be prevented or ameliorated by training, practice, design, performance aids, or procedures changes? NS

.7 To which typical space-mission tasks is performance of this function related? PS

.8 During which portions of a typical space mission is performance of this function required? PS

.9 How is performance of this function affected by spacecraft dynamics (acceleration, rotation, vibration)? 1-BR-1-

.10 How is performance of this function affected by presence or absence of visual cues, using different extremities? 1-BR-1-5

1.1.2.1.1.1.4.3 Orientation Illusions

.1 What is the effect of long-duration spaceflight in producing visual, auditory, and somesthetic illusions? 1-BR-1-5

.2 What is the course of change over time of any observed effects? 1-BR-1-5

.3 Are there significant individual differences? 1-BR-1-5

.4 Can observed effects be prevented by training? NS

.5 Can observed effects be prevented or ameliorated by design or procedures changes? NS

1.1.2.1.1.1.5 Chemical Sense

.1 Do changes occur in long-term spaceflight in the senses of taste and smell (olfaction and gustation)? PS

.2 What is the cause of any changes observed? PS

.3 What is the course of change over time? PS

.4 Are there significant individual differences? PS

.5 How can varying the environment be used to prevent or ameliorate any observed changes? PS

.6 Can observed changes be prevented by training? PS

.7 To which typical mission tasks is this function related? PS

.8 During which portions of typical missions is performance of this function required? PS

1.1.2.1.1.2 Psychomotor

.1 Do changes occur in long-term spaceflight in time required, errors made, and sensitivity and control for perceptual motor manipulation and control functions or force production and control? 1-BR-1-3

.2 What is the cause of any changes observed? NS

.3	What is the course of change over time of any observed changes?	1-BR-1-3
.4	Are there significant differences between individuals in observed changes?	1-BR-1-3
.5	Can observed changes be prevented or ameliorated by design, training, or procedures changes?	NS
.6	What physiological measurements are correlated with changes in this function?	1-BR-1-3
.7	How can changes in this function be predicted?	PS
.8	Can changes be prevented by practice, artificial gravity, or performance aids?	PS
.9	To which typical mission tasks is this function related?	PS
.10	During which portions of typical space missions is performance of this function required?	PS
.11	How can sensing and measuring of changes in this function be automated or mechanized?	NS
.12	How is this function affected by spacecraft dynamics (acceleration, rotation, vibration)?	1-BR-1-3
.13	How quickly will subjects learn to perform this function in orbit as effectively as they did in 1-G?	1-BR-1-3
.14	Are the necessary cues for performing this function different in space than in 1-G?	NS
.15	Are some psychomotor functions more difficult in space than others?	1-BR-1-3
.16	How is performance of this function affected by time constraints requiring performance of the function for extended periods of time (1 sec, 10 sec, 30 sec)?	1-BR-1-3
.17	How is performance of this function affected by differential force loads, speed of reaction, and control/display relationships?	1-BR-1-3

1.1.2.1.1.3 Cognitive

.1	Do changes occur in long-term spaceflight in ability to perform cognitive functions?	1-BR-1-4
.2	What is the cause of any changes observed?	NS

.3 What is the course of change over time? 1-BR-1-4

.4 Are there significant differences between individuals in any observed changes? 1-BR-1-4

.5 Can observed changes be prevented or ameliorated by training, practice, design, performance aids, or procedures changes? NS

.6 How can changes in this function be predicted? NS

.7 What physiological measurements are correlated with changes in this function? 1-BR-1-4

.8 How can sensing and measuring of changes in this function be automated or mechanized? NS

.9 How is performance of this function affected by spacecraft dynamics (acoustics, acceleration, rotation, vibration)? 1-BR-1-4

.10 To which typical mission tasks is performance of this function related? PS

.11 During which portions of typical space missions is performance of this function required? PS

1.1.2.1.2 Human Capabilities

.1 Do changes occur in long-duration spaceflight in operator, maintenance, or scientific investigation capabilities? 1-BR-3

.2 What is the course of change over time of any observed changes? 1-BR-3

.3 Are there significant differences between individuals in observed changes? 1-BR-3

.4 How are personality variables related to individual differences? NS

.5 Can observed changes be prevented or ameliorated by design, training, practice, performance aids, or procedures changes? NS

.6 Which operator, maintenance, and scientific investigation functions are best performed by man? NS

.7 How is human performance of operator, maintenance, and scientific investigation tasks affected by spacecraft dynamics? 1-BR-3

.8 What are the mathematical equations for human performance of various operator, maintenance, and scientific investigation tasks? NS

.9	How can performance of operator, maintenance, and scientific investigation tasks be measured and assessed?	NS
.10	What are the design requirements for controls and displays associated with operator, maintenance, and scientific investigation tasks?	1-MM-1
.11	How can performance of operator, maintenance, and scientific investigation tasks be enhanced by feedback of results?	NS
.12	How can on-board computers be used to assist in performance of operator, maintenance, and scientific investigation tasks?	1-MM-5
.13	How is time stress related to performance of operator, maintenance, and scientific investigation tasks?	1-BR-3
.14	What is the optimum method of storing, retrieving, and presenting reference data for operator, maintenance, and scientific investigation tasks?	1-MM-5

1.1.2.1.3 Group Structure and Dynamics

.1	Do changes occur in long-duration spaceflight in patterning of group processes, in structuring of group roles, or in group attitudes?	1-BR-2
.2	What are the causes of any observed changes?	NS
.3	What is the course of change over time?	1-BR-2
.4	What are the relationships between observed changes and personality characteristics of individual crew members?	1-BR-2
.5	Do groups of different composition show different responses to long-duration spaceflight?	1-BR-2
.6	How can changes be prevented or ameliorated?	1-BR-2
.7	What are the effects of observed changes on mission success?	PS
.8	What effects do observed changes have on crew performance, crew compatibility, morale, and motivation?	1-BR-2
.9	What is the effect of ground communications on group structure and dynamics?	1-BR-2
.10	How do changes in group structure and dynamics affect the effectiveness of leadership?	1-BR-2
.11	What are the requirements for onboard social systems for long-duration spaceflight?	NS

.12 How do habitability design features affect group structure and dynamics? 1-BR-2

.13 How can participation in group activities in long-duration spaceflight be used to support group structure? 1-BR-2

.14 How is reduction of privacy related to group structure and process in long-duration spaceflight? 1-BR-2

.15 How can avenues of escape from interpersonal conflict be provided in long-duration spaceflight? 1-BR-2

1.1.2.1.4 Personal and Social Adjustment

.1 What is the relationship between specific personality traits and changes in indices of adjustment (morale, motivation, frustration, anxiety, hostility, ability to concentrate, fatigue, depression, and withdrawal) in long-duration spaceflight? 1-BR-2

.2 How do individuals whose personality tests suggest social maladjustment, adjust to prolonged spaceflight? NS

.3 How can healthy social adjustment be facilitiated during long-duration spaceflight? 1-BR-2

.4 How can preflight training and orientation be used to promote social adjustment in long-duration spaceflight? NS

.5 Do changes in personality occur during long-duration spaceflight? 1-BR-2

.6 How can social adjustment be measured in long-duration spaceflight? NS

.7 How do morale problems affect crew performance in long-duration spaceflight? 1-BR-2

.8 What is the effect of long-duration spaceflight on personal problem-solving abilities when the familiar modes for problem solving are not available? 1-BR-2

.9 How can effective modes of personal problem solving be provided in long-duration spaceflight? NS

.10 How can feelings of hostility in long-duration spaceflight be prevented or their effects ameliorated? NS

.11 What set of compatible personalities is most effective for long-duration spaceflight? NS

.12 How is social adjustment affected in long-duration spaceflight by the lack of contact with familiar (world news, family problems, significant persons and role partners)? 1-BR-2

.13 How can problems caused by space crews being cut off from familiar surroundings be prevented or alleviated by training, design, or procedure changes? NS

1.1.2.1.5 Selection and Training

.1 What is the effect on crew performance, social adjustment, and individual subjective reactions for various selection criteria? NS

.2 How effective is preflight training on mission success in terms of crew performance, physical fitness, social adjustment, individual behavior, and retention of skills? 1-BR-4

.3 How effective is in-flight training or practice in maintaining seldom-used skills? 1-BR-4

.4 How do specific skills degrade over time in space? 1-BR-4

1.1.2.1.6 Performance Monitoring and Assessment

.1 How sensitive are sampling techniques in identifying differences in performance in long-duration space missions? 1-BR-6

.2 Can measures of task components (such as abilities) be used to validly infer performance on the total task? 1-BR-6

.3 How can operational jobs in long-duration space missions be designed so that significant aspects of behavior can be periodically or continuously assessed? NS

.4 How can independent, uncontaminated criteria of human performance under long-term spaceflight operational conditions be derived? NS

.5 How reliable and valid are various direct, indirect, and subjective methods of monitoring and assessing crew performance in long-duration spaceflight? 1-BR-6

.6 What are the spacecraft support requirements for the various methods of monitoring and assessing performance in long-duration spaceflight? 1-BR-6

.7 How does use of the various methods of monitoring and assessing performance in long-duration spaceflight influence or change the behavior they are attempting to measure? 1-BR-6

.8 How can the various methods of monitoring and assessing performance in long-duration spaceflight be adapted to provide real or near-real-time evaluation of crew performance? NS

1.1.2.2 Man-Machine Research

1.1.2.2.1 Controls and Displays

.1 How valid are traditional control and display design principles under conditions of long-duration spaceflight? 1-MM-1

.2 How is man's capability to handle information affected by the amount and type of data presented under conditions of long-duration spaceflight? 1-MM-1

.3 How effective are nonvisual displays in presenting status, trend, and alerting information? 1-MM-1

.4 What is the maximum capacity of the man-display combination for time sharing? 1-MM-1

.5 What display characteristics are incompatible with crew performance capabilities? 1-MM-1

.6 How can man's capabilities for communicating with computers be enhanced by optimum controls and displays? 1-MM-1

.7 What is the optimum combination of alpha and numeric symbology for CRT displays in long-duration spaceflight? 1-MM-1

.8 What are the spacecraft support requirements for various types of displays and controls? 1-MM-1

.9 What is optimum spacecraft ambient lighting for use with electroluminescent displays? 1-MM-1

.10 How can time-shared displays be used to reduce space and power requirements while enhancing crew performance? 1-MM-1

.11 How can nonessential indications on displays be eliminated? 1-MM-1

.12 What is the optimum mix of situation displays and discrete indicators? 1-MM-1

.13 What are the design requirements for a device to permit crew members to evaluate photographic data onboard and to edit, crop, or reject prior to transmission? 1-MM-1

.14 What is the optimum arrangement of controls and displays at a single work station to permit control of a number of experiments, subsystem operations, maintenance actions, or vehicle control? 1-MM-1

1.1.2.2.2 Locomotion and Restraint

.1 What is metabolic cost of work under various conditions of locomotion and restraint? 1-MM-2

.2 What are the acceleration profiles under various locomotion conditions? 1-MM-2

.3 How are crew dexterity, ability to apply forces, reach envelopes, visual span, and maintenance ability affected by various restraint techniques? 1-MM-2

.4 What are the restraint and locomotion requirements for partial g compared with zero g? 1-MM-2

.5 What is optimum restraint method for extended-duty work station? 1-MM-2

.6 How is sleep effectiveness affected by various sleep-station restraint methods? 1-MM-2

.7 What are the advantages and disadvantages of powered vs. unpowered locomotion devices in terms of metabolic cost, encumbrance to crew activities, accuracy of path, control of acceleration and deceleration, safety from personal injury, or equipment damage? 1-MM-2

.8 How do various restraint devices compare in terms of demands on crew time? 1-MM-2

.9 What spacecraft support requirements are imposed by the various restraint and locomotion techniques and equipment? 1-MM-2

.10 What are the dynamics of a tethered crewman for various tether lengths? 1-MM-2

.11 What is optimum size and shape for cargo items to be transported in space by crewman using various locomotion techniques? 1-MM-2

1.1.2.2.3 Habitability

.1 What is effect of time in orbit on volume requirements? 1-MM-3

.2 How do volume, configuration, and privacy provisions affect crew adjustment? 1-MM-3

.3 What is effect on crew performance and adjustment of changing volume and configuration periodically? 1-MM-3

1.1.2.2.3.2 Environment

.1 How does sleep station design affect crew performance and adjustment? 1-MM-3

.2 What level of artificial gravity is optimum? 1-MM-3

.3 How does illumination affect crew performance and adjustment? 1-MM-3

.4 What effect do color and decor have on crew effectiveness? 1-MM-3

.5 What are the optimum comfort criteria (e.g., temperature, humidity, air flow)? 1-MM-3

.6 How does the acoustic environment affect crew performance and adjustment? 1-MM-3

.7 What equipment and procedures are optimum for crew health maintenance? 1-MM-3

.8 How do crew attitudes toward habitability features change over time in long-duration spaceflight? 1-MM-3

.9 How effective is preflight training in conditioning crew to accept habitability features? 1-MM-3

.10 What are the physiological and psychological requirements for frequency of use of habitability provisions? 1-MM-3

.11 What are the spacecraft support requirements imposed by various habitability features? 1-MM-3

1.1.2.2.3.3 Personal Support

.1 How do nutritional requirements change over time in space? 1-MM-3

.2 What is optimum in-flight physical fitness program? 1-MM-3

.3 How do provisions for recreation and leisure affect crew performance and adjustment? 1-MM-3

.4 What are optimum personal-hygiene facilities? 1-MM-3

1.1.2.2.4 Work/Rest/Sleep Cycles

1.1.2.2.4.1 Rhythms and Cycles

.1 How do circadian rhythms change in long-duration spaceflight? 1-MM-4

.2 What is the effect of circadian changes on crew performance? 1-MM-4

.3 How can adverse effects of circadian changes be prevented or ameliorated? 1-MM-4

1.1.2.2.4.2 Sleep

.1 What is the effect of time in orbit on sleep requirements? 1-MM-4

.2 How is sleep effectiveness affected by external factors (such as noise, acceleration, illumination)? 1-MM-4

.3 How effective are short sleep periods (4 hours to cat-napping) in meeting sleep needs in long-duration spaceflight? 1-MM-4

.4 What are the advantages and disadvantages of simultaneous sleep? 1-MM-4

.5 What is the effectiveness (or need) of artificially induced sleep? 1-MM-4

.6 What is the pattern of sleep stages over time in orbit? 1-MM-4

1.1.2.2.4.3 Work/Rest

.1 What is the optimum on-off work schedule in long-duration spaceflight? 1-MM-4

.2 How do work/rest requirements change over time in long-duration spaceflight? 1-MM-4

.3 What is the effect on crew performance and adjustment of the altered day/night cycles of space? 1-MM-4

.4 How long does it take crew members in space to adjust to altered day/night cycles, and what is the pattern of individual differences? 1-MM-4

1.1.2.2.5 Performance Aids

1.1.2.2.5.1 Tools

.1 What are the design and storage requirements for tools on long-duration spaceflight? 1-MM-5

.2 How effective are multipurpose tools, special tools, and standard 1-g tools, and how can tool requirements be reduced? 1-MM-5

.3 What are prime equipment design requirements imposed by tools and remote manipulators? 1-MM-5

1.1.2.2.5.2 Manipulators and Force Assistive Devices

.1 What is the effect of the spaceflight environment on design requirements for remote manipulators? 1-MM-5

.2 How do task time requirements differ for direct vs. remote manipulators? 1-MM-5

.3 What feedback is required for operators of remote manipulators? 1-MM-5

1.1.2.2.5.3 Computer Aids and Checklists

.1 What is relative value of visual vs. auditory checklists in long-duration spaceflight? 1-MM-5

.2 How effective are computer performance aids? 1-MM-5

.3 How effective are various optical aids in enhancing performance? 1-MM-5

.4 What are the dynamics of tethered tools in weightlessness? 1-MM-5

1.1.2.2.6 Scheduling Techniques

.1 How effective are fixed vs. flexible schedules? PS

.2 What is the optimum time base for mission scheduling? PS

.3 How can an onboard computer be used to facilitate schedule construction and updating? PS

.4 What is the optimum method for onboard storage, retrieval, and presentation of schedule information? PS

.5 How detailed do onboard schedules have to be? PS

.6 What is the optimum method for updating schedules? PS

.7 How effective is preflight training on schedule construction and updating, and what should be the content, duration, and techniques for such training? PS

.8 How effective are ground communications in the updating of onboard schedules, and how should this effort be apportioned between ground and onboard crew? PS

.9 How does format of schedule and means of presentation affect the way in which crew performs scheduled activities? PS

1.1.3 LIFE SUPPORT AND PROTECTIVE SYSTEMS

1.1.3.1 <u>Development of Atmospheric Supply and Pressure System Technology</u>

1.1.3.1.1 Atmosphere Supply

1.1.3.1.1.1 Storage

1.1.3.1.1.1.1 Chemical

.1 What are the operational aspects and/or interfaces of chlorate candles, ozonites, and super-oxide for the supply of nitrogen and hydrogen, and how are they affected by zero-g conditions? 1-LS-3

.2 What mass transfer phenomena in the diffusion of product from sources and in separation processes occur under spaceflight conditions? 1-LS-2

.3 What heat transfer problems in thermal decomposition of chemicals require investigation under spaceflight conditions? 1-LS-1

.4 What material types need to be investigated and/or developed in conjunction with chemical storage of atmospheric gases for spacecraft applications? 1-LS-3

.5 What are the basic physical processes involved in the chemical storage of atmospheric gases and how are they altered under zero-g conditions? 1-LS-3

1.1.3.1.1.1.2 Gaseous

.1 What are the operational problems of gaseous storage systems for the supply of oxygen, nitrogen and hydrogen, and what changes occur under zero-g conditions? 1-LS-3

1.1.3.1.1.1.3 Cryogenic Storage

.1 What thermodynamic processes are involved in the delivery of cryogenically stored oxygen and nitrogen in a space environment? 1-LS-1 1-LS-2

.2 What is the long-term effectiveness of present cryogenic storage methods? 1-LS-10

.3 What are the characteristics of fluid gaging and management in cryogenic atmosphere supply systems? 1-LS-8

.4 What control sensors are needed for long-duration operation of two-gas atmosphere systems? 1-LS-8

.5 What are the density profile characteristics of liquids at and near the critical state? 1-LS-1

.6 How can gas-free cryogenic liquid transfer and maintenance be achieved in zero-g? 1-LS-1

.7 What zero-g interface phenomena of liquid-gas systems are involved in cryogenic storage of atmospheric gases? 1-LS-2

.8 What are the zero-g kinetic and dynamic characteristics of gas bubbles and how do they influence the operation of cryogenic stores? 1-LS-2

.9 What integrated cryogenic storage subsystem tests are needed for operation verification in the space environment? 1-LS-3

.10 What are the consequences of the vapor purge of cryogenic liquid systems in zero-g? 1-LS-2

1.1.3.1.1.2 Oxygen and Diluent Supply

1.1.3.1.1.2.1 Carbon Dioxide Decomposition

1.1.3.1.1.2.1.1 Solid Electrolyte

.1 What are the space effects on electrochemical reactions involved in the operation of the solid electrolyte reactor? 1-LS-3

.2 What are the zero-g heat transfer problems involved in the operation of the solid electrolyte reactor? 1-LS-1

.3 What are the zero-g effects of the carbon accumulation problem on the operation of the solid electrolyte cell? 1-LS-3

.4 How will zero-g affect the materials used for solid electrolyte cell electrodes? 1-LS-3

.5 How does zero-g affect solid electrolyte components? 1-LS-3

.6 How does zero-g affect the presence of water vapor in the CO_2 stream on the solid electrolyte reaction? 1-LS-1

1.1.3.1.1.2.1.2 Molten Carbonate

.1 How are the elctrochemical reactions of the molten carbonate reactor system affected in the space environment? 1-LS-3

.2 What are the effects of zero-g heating on the operation of the molten carbonate reactor? 1-LS-10

.3 How does weightlessness affect the carbon accumulation and the operation of the molten carbonate reactor? 1-LS-3

.4 How does the presence of water vapor in the CO_2 stream affect the molten carbonate reaction in a weightless environment? 1-LS-1

.5 How does zero-g affect the materials used for the molten carbonate cells? 1-LS-3

.6 What electrolyte is most suitable for the operation of molten carbonate reaction in a space environment? 1-LS-3

.7 What are the handling problems involved with the carbonate melt in a weightless environment? 1-LS-3

.8 What are the zero-g operational effects on the gas-liquid-solid system involved in the molten carbonate reactor? 1-LS-2

.9 How does a space environment affect the molten carbonate components? 1-LS-3

1.1.3.1.1.2.2 Carbon Dioxide Reduction/Electrolysis

1.1.3.1.1.2.2.1 Carbon Dioxide Reduction

1.1.3.1.1.2.2.1.1 Sabatier

.1 What are the zero-g heat transport problems involved in the operation of the Sabatier reactor? 1-LS-10

.2 How does zero-g affect the gas-liquid separation characteristics of the effluents from the Sabatier reactor and condenser? 1-LS-2

.3 How does a space environment affect the mechanisms involved in the Sabatier reaction? 1-LS-3

.4 How does zero-g influence the partial cracking of methane? 1-LS-3

.5 How does zero-g influence the full cracking of methane? 1-LS-3

.6 How does a space environment affect the operation of Sabatier components? 1-LS-3

1.1.3.1.1.2.2.1.2 Bosch

.1 What are the zero-g heat transfer problems involved in the operation of the Bosch reactor? 1-LS-10

.2 How does weightlessness influence the gas-liquid separation characteristics of the effluents from the Bosch reactor and condenser? 1-LS-2

.3 What are the zero-g effects of the carbon accumulation on the operation of the Bosch reactor? 1-LS-3

.4 What are the effects of zero-g on characteristics and mechanisms involved in the Bosch reaction? 1-LS-3

.5 How does a space environment affect the operation of the Bosch components? 1-LS-3

1.1.3.1.1.2.2.2 Water Electrolysis

1.1.3.1.1.2.2.2.1 Liquid/Membrane

.1 How are the electrochemical reactions involved in the operation of water electrolysis cells affected by spaceflight conditions? 1 LS 5

.2 What are the gas-liquid interface problems in liquid/membrane electrolysis units caused by zero-g? 1-LS-1,2

.3 What are the zero-g effects on materials required for water electrolysis cells? 1-LS-5

.4 What are the zero-g effects of gas bubbles in the water electrolysis process? 1-LS-1,2

.5 How does zero-g influence the electrolytes used for water electrolysis? 1-LS-5

.6 How does zero-g affect the electrolysis cell components? 1-LS-5

1.1.3.1.1.2.2.2.2 Vapor Phase

.1 What are the zero-g effects on the optimum operational modes of water vapor electrolysis? 1-LS-5

.2 How does weightlessness influence the effectiveness of humidity control by water vapor electrolysis on the spacecraft life support system operation? 1-LS-7

1.1.3.1.2 Cabin Atmosphere Pressure Control

1.1.3.1.2.2 Dual Gas Atmosphere Pressure Control System

.1 How will zero-g affect dual gas atmosphere pressure control when using polarographic sensors? 1-LS-3,8

.2 How will zero-g affect dual-gas atmosphere pressure control when using paramagnetic sensors? 1-LS-3,7

.3 How does zero-g affect dual-gas atmosphere pressure control when using mass spectrometers? 1-LS-3,8

.4 How does zero-g affect dual-gas atmosphere pressure control when using gas chromatographs? 1-LS-3,8

1.1.3.2 <u>Atmosphere Purification and Control</u>

1.1.3.2.1 Carbon Dioxide

1.1.3.2.1.4 Concentration

1.1.3.2.1.4.1 Electrodialysis

.1 What are the electrochemical problem areas associated with zero-g operation of electrodialysis CO_2 collection units? 1-LS-7

.2 What are the gas-liquid separation problems associated with the zero-g operation of the electrodialysis CO_2 collectors? 1-LS-2

.3 What electrolytes are best for use in zero-g electrodialysis CO_2 collection units? 1-LS-7

.4 How are electrodialysis CO_2 collector components affected in space? 1-LS-7

1.1.3.2.1.4.2 Solid Amines

.1 What are the zero-g mass transport characteristics of solid amines? 1-LS-2,7

.2 What are the heat transfer problems involved in the zero-g operation of solid amine CO_2 collection units? 1-LS-10

.3 How does a weightless environment affect the water vapor control required in the operation of solid amine CO_2 collectors? 1-LS-7

.4 How does a space environment affect the operation of the solid amine components? 1-LS-7

1.1.3.2.1.4.3 Molecular Sieves

.1 How does zero-g influence the mass transfer parameters involved in the molecular sieve CO_2 collectors? 1-LS-2

.2 How does weightlessness affect the heat transfer conditions involved in the molecular sieve CO_2 collectors? 1-LS-1

.3 How does zero-g affect the molecular sieve CO_2 collector components? 1-LS-7

.4 What is the effect of a space environment on integrated molecular sieve CO_2 collector subsystems? 1-LS-7

1.1.3.2.1.4.4 Liquid Absorption

.1 How does zero-g influence the chemical reactions in a liquid absorption CO_2 collector? 1-LS-7

.2 How do space conditions affect materials required in a liquid absorption CO_2 collector? 1-LS-7

.3 How does zero-g influence the interface problems and devices involved in liquid absorption CO_2 collectors? 1-LS-1,2

.4 What are the mixing characteristics of liquids in zero-g and how do they affect the liquid absorption CO_2 collectors? 1-LS-2

.5 What are the zero-g absorption characteristics of gases by liquids and how do they affect the liquid absorption CO_2 collector? 1-LS-1

.6 How does zero-g affect the liquid absorption subsystem and components? 1-LS-7

1.1.3.2.1.4.5 Carbonation Cell

.1 What are the zero-g effects on electrochemical transport parameters in carbonation cells? 1-LS-7

.2 What are the zero-g effects on heat transfer conditions in carbonation cells? 1-LS-10

.3 How does weightlessness affect the electrolyte to be used in carbonation cells? 1-LS-7

.4 What are the zero-g effects on carbonation cell subsystem or components? 1-LS-7

1.1.3.2.2 Trace Contaminants

1.1.3.2.2.3 Removal

.1 How does zero-g affect trace contaminants removal by nonregenerable sorbers and what are the effects on conceptual configurations? 1-LS-7

.2 How does zero-g affect tract contaminants removal by regenerable sorbers and what are the effects on conceptual configurations? 1-LS-7

1.1.3.2.2.4 Catalytic Oxidation

.1 What are the zero-g effects on catalytic oxidation of trace contaminants by high temperature catalytic burners and how do they influence the conceptual configurations? 1-LS-7

.2 What are the zero-g effects on catalytic oxidation of trace contaminants by low temperature catalytic burners and how do they influence the conceptual configurations? 1-LS-7

1.1.3.2.3 Humidity

1.1.3.2.3.3 Condensation/Separation

1.1.3.2.3.3.2 Separation

.1 How does a weightless environment influence humidity control methods? 1-LS-7

.2 How does zero-g affect gas liquid separation involved in humidity control subsystems? 1-LS-2

.3 What are the effects of zero-g on heat transfer involved in humidity control subsystems? 1-LS-10

.4 How does zero-g affect the humidity control subsystem components? 1-LS-8

1.1.3.2.4 Aerosols

1.1.3.2.4.2 Removal

1.1.3.2.4.2.1 Filtration

.1 What are the zero-g effects on aerosol filtration subsystems under spaceflight conditions? 1-LS-7

.2 How does zero-g influence an aerosol control subsystem? 1-LS-7

1.1.3.2.4.2.2 Precipitation

.1 How does a space environment affect the performance of aerosol precipitation subsystems? 1-LS-7

.2 What is the effect of zero-g on an aerosol control subsystem? 1-LS-7

1.1.3.2.4.2.3 Centrifugation

.1 How does zero-g affect aerosol centrifugation subsystems? 1-LS-7

.2 What is the influence of weightlessness on an aerosol control subsystem? 1-LS-7

1.1.3.3 Thermal Control

1.1.3.3.1 Passive Thermal Control

1.1.3.3.1.1 Insulation

1.1.3.3.1.1.1 High-Vacuum Insulation

.1 How does zero-g influence the convection heat transfer in high-vacuum insulation? 1-LS-10

.2 How does zero-g affect the diffusion convection processes occurring in conjunction with entrapped gases in high-vacuum insulation? 1-LS-2

1.1.3.3.1.1.2 Ablative Insulation

.1 What are the effects of a space environment on the diffusion convection processes occurring in conjunction with ablative insulation subsystems? 1-LS-1,2

.2 How does zero-g affect the convection heat balances in ablative insulations? 1-LS-10

.3 How does zero-g influence the chemical reaction rates in ablative insulation systems? 1-LS-10

1.1.3.3.1.1.3 Conduction Insulation

.1 What is the influence of a space environment on heat path characteristics of conduction type insulation used in a space vehicle structure? 1-LS-10

1.1.3.3.1.2 Radiative Surfaces

1.1.3.3.1.2.1 Fixed Surfaces

.1 How does a space environment influence materials on fixed radiative surface systems? 1-LS-10

1.1.3.3.1.2.2 Variable Surfaces

.1 What are the effects of space on mechanisms and materials used with variable surface insulation? 1-LS-10

1.1.3.3.1.3 Heat Pipes

.1 What are the effects of zero-g on heat transfer involved in boiling and/or condensation processes in heat pipes? 1-LS-2

.2 What are the zero-g influences on mass transfer diffusion processes in heat pipes? 1-LS-2

.3 What are the zero-g effects on fluid flow characteristics involved in capillary transport processes in heat pipes? 1-LS-2

1.1.3.3.2 Active Thermal Control

1.1.3.3.2.1 Heating Systems

1.1.3.3.2.1.1 Heat Storage Systems

1.1.3.3.2.1.1.1 Phase Change

.1 How does zero-g affect solar heat collectors and interfaces with the heat storage systems? 1-LS-10

.2 How does a space environment influence waste heat utilization in heat storage systems? 1-LS-10

.3 How does a space environment affect heat storage components? 1-LS-10

.4 What are the effects of zero-g on liquid/solid/gas separation devices? 1-LS-2

.5 What are the effects of a space environment on phase-change substances used in heat storage systems? 1-LS-1

1.1.3.3.2.1.1.2 Single Phase

.1 How does a space environment influence the applications, heat load, and temperature ranges used in a single-phase heat storage system? 1-LS-10

.2 What are the effects of zero-g on single-phase storage systems and components? 1-LS-10

1.1.3.3.2.1.2 Fluid Transport Systems

.1 What are the effects of a space environment on radioisotope management and control characteristics used with fluid transport systems? 1-LS-10

1.1.3.3.2.2 Cooling Systems

1.1.3.3.2.2.1 Heat Sinks

1.1.3.3.2.2.1.2 Radiative Cooling

1.1.3.3.2.2.1.2.1 Condensing

.1 How does zero-g influence the condensing heat transfer characteristics in space radiators? 1-LS-10

.2 How does zero-g affect the configurations of condensing space radiators? 1-LS-10

.3 What are the effects of zero-g on liquid/gas separators used with condensing radiator systems? 1-LS-2

1.1.3.3.2.2.2 Fluid Transport Systems

1.1.3.3.2.2.2.2 Condensers

.1 How does zero-g affect condensing heat transfer? 1-LS-1,10

.2 What are the effects of a space environment on liquid/gas separation condenser systems? 1-LS-2,10

1.1.3.4 Water Management

1.1.3.4.1 Storage/Preservation

1.1.3.4.1.1 Bladder Tank Storage

.1 How does zero-g influence mass transfer in the diffusion of liquids and/or gases through the tank bladders? 1-LS-2,4

.2 How do zero-g conditions affect fluid flow characteristics of expulsion gas and water involved in bladder tank storage? 1-LS-2,4

1.1.3.4.1.2 Chemical Preservation

.1 What are the effects of zero-g on mass transfer involved in dissolution, mixing, plating out, and decomposition processes occurring in chemical preservation of water? 1-LS-4

.2 How does zero-g influence fluid flow characteristics of chemical preservation methods of water storage? 1-LS-2

1.1.3.4.1.3 Pasteurization

.1 What are the effects of zero-g on the modes of heat transfer involved in maintaining the water temperature (between 100° and 160°F) with the pasteurization process? 1-LS-4

1.1.3.4.2 Reclamation

1.1.3.4.2.1 Membrane/Filtration

.1 What are the zero-g effects on the flow regime characteristics in water filtration processes? 1-LS-2,4

.2 What are the effects of zero-g on gas/liquid separation problems in water filtration processes? 1-LS-2

.3 How does a zero-g environment influence the mixing characteristics of fluids in the filtration processes? 1-LS-2

.4 How does zero-g affect the filtration process components and/or subsystems? 1-LS-4

.5 What are the effects of a space environment on the flow regime characteristics in the reverse osmosis process? 1-LS-2

.6 What are the zero-g effects on gas/liquid separation devices in the reverse osmosis process of reverse-osmosis water-recovery units? 1-LS-2

.7 How does zero-g affect the mixing characteristics of fluids in the reverse osmosis process? 1-LS-2

.8 How does zero-g influence the design of reverse osmosis components? 1-LS-4

1.1.3.4.2.2 Phase Change

1.1.3.4.2.2.1 Air Evaporation

.1 What are the zero-g boiling heat transfer problems in the air evaporation process? 1-LS-1,4

.2 How does zero-g affect the flow regime characteristics in the air evaporation process? 1-LS-2

.3 What are the effects of zero-g on the mixing characteristics of fluids used in the air evaporation process? 1-LS-2

.4 What are the zero-g effects on the gas/liquid separation devices used in the air evaporation process? 1-LS-4

.5 How does zero-g affect air evaporation components? 1-LS-4

.6 What are the space effects on an integrated air evaporation system? 1-LS-4

1.1.3.4.2.2.2 Vapor Diffusion

.1 What are the zero-g heat transfer effects involved in a vapor diffusion process? 1-LS-1,4,10

.2 What are the zero-g effects on membrane diffusion used in conjunction with vapor diffusion process? 1-LS-4

.3 How does a space environment affect gas/liquid separation in the vapor diffusion process? 1-LS-4

.4 What are the space effects on the operation of the vapor diffusion unit? 1-LS-4

1.1.3.4.2.2.3 Vapor Diffusion Compression

.1 What are the effects of zero-g on heat transport in the vapor diffusion compression process? 1-LS-1,4,10

.2 How does zero-g influence gas/liquid separation devices in the vapor diffusion compression process? 1-LS-4

.3 What are the zero-g effects on vapor diffusion compression components? 1-LS-4

.4 What are the zero-g influences on the operation of the integrated vapor-diffusion-compression water-recovery system? 1-LS-4

1.1.3.4.2.2.4 Vapor Pyrolysis/Catalysis

.1 What are the space effects on heat transfer problems in the vapor pyrolysis process? 1-LS-1,4,10

.2 What are the zero-g effects on gas/liquid separation in the vapor pyrolysis process? 1-LS-4

.3 What are the effects of zero-g on vapor pyrolysis components ? 1-LS-4

.4 How does zero-g influence the design of the integrated vapor pyrolysis water-recovery system? 1-LS-4

1.1.3.4.2.2.5 Vapor Compression

.1 How does zero-g affect heat-transfer vapor compression process? 1-LS-1,4,10

.2 What are the zero-g effects on the flow regime in the vapor compression process? 1-LS-4

.3 What are the zero-g effects on the gas/liquid separation devices used in the vapor compression process? 1-LS-2

.4 What is the effect of zero-g on the vapor compression components? 1-LS-4

.5 What are the effects of space on the performance of the integrated vapor compression system? 1-LS-4

1.1.3.5 Waste Management

1.1.3.5.1 Collection

1.1.3.5.1.1 Urine

.1 What are the zero-g phase separation and liquid fluid flow characteristics involved in urine collection? 1-LS-2,9

1.1.3.5.1.2 Feces/Refuse

.1 What are the zero-g flow characteristics involved in feces and refuse collection? 1-LS-2,9

1.1.3.5.2 Incineration

.1 How does zero-g influence mass transfer in waste management incineration? 1-LS-2,9

.2 What are the zero-g fluid flow characteristics of combustion products and oxygen in the incineration waste management system? 1-LS-2

.3 What are the influences of zero-g on the heat transfer phenomena involved in the burning processes in waste management incineration? 1-LS-1

1.1.3.5.3 Storage

1.1.3.5.3.1 Urine

.1 What are effects of zero-g on the basic processes involved in urine storage in waste management systems? 1-LS-3,9

.2 How does zero-g affect chemical and freeze urine storage methods? 1-LS-9

.3 What are the affects of space on the mixing characteristics used in conjunction with urine storage? 1-LS-2

.4 What are the zero-g effects on mass and heat transfer involved in urine storage? 1-LS-1,2

1.1.3.5.3.2 Feces/Refuse

.1 What are the space effects on fluid flow in conjunction with drying and/or mixing in feces and refuse storage systems? 1-LS-1,9

.2 What are the effects of zero-g on heat and mass transfer involved in drying and mixing processes of feces and refuse? 1-LS-2

1.1.3.6 Food Management

1.1.3.6.1 Stored Food

1.1.3.6.1.1 Freeze-Dried

.1 What are the effects of zero-g on mixing of solids and/or liquids in stored freeze-dried food management processes ? 1-LS-2,6

.2 How does zero-g influence the interfaces of stored freeze-dried food and water management systems? 1-LS-6

.3 What are the zero-g effects on stored freeze-dried food management system components? 1-LS-6

.4 What are the effects of zero-g on stored freeze-dried food management subsystem? 1-LS-6

1.1.3.6.1.2 Frozen

.1 What are the zero-g effects on the use of frozen foods on spacecraft water balance, water recovery system, and logistic problems? 1-LS-6

.2 What are the zero-g effects on refrigeration requirements needed for frozen food system? 1-LS-6

1.1.3.6.1.3 Irradiated or Canned

.1 What are the space influences on the irradiated or canned food system? 1-LS-6

.2 How does zero-g affect the interfaces of the irradiated or canned food system with the water and waste management systems? 1-LS-6

1.1.3.6.2 Regenerative

1.1.3.6.2.1 Chemical Synthesis

.1 What are the space effects on catalysts used in the chemical synthesis reaction chambers? 1-LS-6

.2 What are the zero-g effects on the yield obtained from the glycerol food process? 1-LS-6

.3 How does zero-g influence the carbon dioxide requirements of the chemical synthesis system? 1-LS-6

.4 How does zero-g affect the high-pressure processes involved in chemical synthesis food regeneration system? 1-LS-6

1.1.3.6.2.2 Biological Regeneration

.1 What are the effects of a space environment on gas/liquid separation involved in biological food regeneration process? 1-LS-2,6

.2 What are the zero-g effects on solid/liquid separation in processed biological food management? 1-LS-2,6

.3 How does a space environment influence culture growth processes in processed biological food management? 1-LS-6

.4 What are the effects of zero-g on processed biological food management system components? 1-LS-6

.5 What are the effects of a space environment on the processed biological food management subsystem? 1-LS-6

1.1.3.7 <u>Crew Protective Systems</u>

1.1.3.7.1 Internal Hazards

1.1.3.7.1.1 Fire

.1 What are the zero-g effects on the spacecraft atmosphere dump subsystem? 1-LS-11

.2 How does zero-g affect the carbon dioxide fire control subsystem under spaceflight conditions? 1-LS-11

.3 What are the effects of zero-g on a fluorocarbon fire control subsystem? 1-LS-11

.4 What are the effects of zero-g on an inert gas, flood-fire control subsystem under spaceflight conditions? 1-LS-11

1.1.3.7.1.2 Atmosphere Contaminant Control

(Refer to Section 1.1.3.2)

1.1.3.7.1.3 Thermal Protection

(Refer to Section 1.1.3.3)

1.1.3.7.1.4 Biological Control

.1 What is the effect of zero-g on the personal hygiene subsystem? 1-LS-11

.2 What are the zero-g effects on the first aid subsystem? 1-LS-11

1.1.3.7.2 External Hazards

1.1.3.7.2.1 Zero Gravity

.1 What changes occur in the operation of the artificial gravity subsystem (centrifuge and/or vehicle rotation) under spaceflight conditions? 1-LS-11

.2 What changes occur in the operation of the cardiovascular conditioning subsystem under spaceflight conditions? 1-LS-11

1.1.3.7.2.2 Radiation

.1 What are the space effects on the radiation shielding subsystem? 1-LS-11

.2 What are the space effects on the radiation shelter subsystem? 1-LS-11

.3 What are the space effects on radiation suits? 1-LS-11

1.1.3.7.2.3 Meteoroids

.1 How does space affect the various methods of rapid repressurization of spacecraft cabins? 1-LS-11

.2 What are the effects of space on the leak detection subsystem? 1-LS-11

.3 What are the space effects on the leak repair subsystem? 1-LS-11

.4 What are the space effects on the EVA suit subsystem? 1-LS-11

1.1.3.7.2.4 Vacuum

.1 What are the effects of space vacuum on crew protection by the use of the atmospheric supply and purification system functions? 1-LS-11

.2 How does a space environment influence the flexible-airlock and space-suit subsystems? 1-LS-11

.3 What are the space effects on the leak detection and repair subsystem for protection from space vacuum? 1-LS-12

1.1.3.8 Integrated Life Support Systems

.1 What are the zero-g effects on maintenance and repair procedures? 1-LS-12

.2 What are the zero-g effects on the EC/LS system controls? 1-LS-8

.3 What are the space effects on an integrated animal EC/LS system? 1-LS-3 thru 12

.4 What are the space effects on the integrated EC/LS system and power? 1-LS-3 thru 12

.5 How does space affect an integrated life support system? 1-LS-3 thru 12

1.2 ENGINEERING EXPERIMENTS

1.2.1 DATA MANAGEMENT SUBSYSTEMS

1.2.1.1 Computers

1.2.1.1.1 Digital (See 1.2.1.1.3)

1.2.1.1.2 Analog (See 1.2.1.1.3)

1.2.1.1.3 Hybrid

.1 What are the performance requirements of the (digital, analog, hybrid, or special purpose) computers? PS

.2 What computing tasks will be assigned to the (digital, analog, hybrid, or special purpose) computers? PS

.3 What are the size and power requirements of the (digital, analog, hybrid, or special purpose) computers? PS

.4 What are the affects of zero-g operation on the (digital, analog, hybrid, or special purpose) computers? PS

.5 What specialized maintenance problems exist in space vehicle operation for the (digital, analog, hybrid, or special purpose) computers? PS

.6 What environmental loads will result from the (digital, analog, hybrid, or special purpose) computer operations? NS

.7 What output formats (digital, analog, hybrid, or special purpose) are available, and which of these are suitable for the space vehicle requirements? PS

.8 What (digital, analog, hybrid, or special purpose) computers are available for the space vehicle tasks, and what modifications will be necessary for the experiment technology required? PS

.9 What space vehicle operational skills will be required to run the computers, or is it advisable for each investigator to be trained to run the (digital, analog, hybrid, or special purpose) computers for his own work? 1-OE-5

.10 What are the development and flight qualification problems, and respective costs for the space vehicle (digital, analog, hybrid, or special purpose) computers? PS

.11 What (digital, analog, hybrid, or special purpose) computer requirements of Space Medicine (Paragraph 1.1), Operations Experiments (Paragraph 1.3), and normal house keeping can be consolidated as hopefully one centralized master computing facility? 1-OE-5

.12 What special maintenance and/or operation problems will arise from computer operation at zero-g, and can these be accomplished within the assigned time constraints? PS

.13 What computer contributions can be made to mental recreational games during long space vehicle tours of duty? 1-MM-5

1.2.1.2 Specialized Data Processors

1.2.1.2.1 Converters

.1 What A to D, D to A, temporary to permanent, permanent to temporary, etc., converters will be required for the centralized computer facility? PS

.2 What are the task, performance, size, weight, and power requirements for these converters? PS

.3 What are the zero-g, environmental load, logistic support, and maintenance requirements for these converters? PS

.4 What converters are available for the space vehicle tasks, and what modifications will be necessary for the experiment technology required? PS

.5 What are the development and flight qualification problems, and respective costs for the space vehicle converters? PS

.6 What are the converter requirements of Space Medicine (Paragraph 1.1), Operations Experiments (Paragraph 1.3), and normal house-keeping; and can these requirements be consolidated? PS

.7 What space vehicle instruments or instrumentation subsystems would perform more useful functions if dual-unit converters were provided; for example, a scientist and an engineer trying to make a quick experiment decision where one was familiar with metric units and the other with English units? PS

1.2.1.2.2 Optical Readers

.1 What types of optical readers will be required on the space vehicle; will these be optical projection and/or CRT? PS

.2 What computer outputs may be considered for these readers; for example, digital or analog, or photographic film from temporary or permanent storage? PS

.3 What size viewing screens will be required; for example, large size for multiple viewing, or page size or smaller for a single investigator? NS

.4 What are the weight, power, environment, maintenance, and logistic support for these readers? PS

.5 What are the current state-of-the-art and the development and cost projections for these readers through flight qualification? PS

.6 What are the optical reader requirements of Space Medicine (Paragraph 1.1), Operation Experiments (Paragraph 1.3), and normal house-keeping; and can these requirements be consolidated? 1-OE-5

.7 What advantages could be derived from a pocket-type optical and/or CRT reader that could be plugged into special outlets throughout the space vehicle? PS

.8 What type of personal and/or group microfilm reader, and what kind of film retrieval techniques will be required on the space vehicle? 1-EE-1

.9 What are the requirements of an onboard scientific and recreational microfilm library, and what retrieval techniques will be utilized? 1-MM-5

1.2.1.2.3 Personal Calculators

.1 What kind of desk-type electronic calculators would be required for the space vehicle; for example, a calculator with the provision of recording an accumulation of use time in several categories, such as emergency problem solution, input preparation for main computer, low-level assistance in experiment, station problems, recreational problems, etc? PS

.2 What special requirements of power, weight maintenance, logistic support, and zero-g operation will be imposed on the space vehicle? PS

.3 What special-purpose slide rules, nomographs, tables, and charts will be required to support the experiment programs. PS

.4 What personal calculators will be required to support Space Medicine (Paragraph 1.1), Operations Experiments (Paragraph 1.3), and normal house-keeping; and which of these requirements can be consolidated? 1-OE-5

1.2.1.2.4 Multiplexers

.1 What kind of digital multiplexing will be required for both computer input and output? NS

.2 What kind of analog multiplexing will be required for both computer input and output? NS

.3 What buffer storage requirements will be imposed upon the digital and analog multiplexing? NS

.4 How good are ground test contingency predictions in .1 through .3, as related to actual flight usage? PS

.5 What are the weight, power, environment, maintenance, and logistic support for these multiplexers? PS

.6 What are the current state-of-the-art and the development and cost projections for these multiplexers through flight qualification? PS

.7 What are the multiplex requirements of Space Medicine (Paragraph 1.1), Operations Experiments (Paragraph 1.3), and normal house-keeping; and which of these requirements can be consolidated on a noninterference basis? 1-OE-5

.8 How can man control the possibility of multiplexer and/or buffer storage overload by slight or major schedule shifts? PS

1.2.1.2.5 Time Generators

.1 What time base(s) will be required on the space vehicle; for example, realtime, experiment repetitive time, Earth zonal time, siderial time? PS

.2 What time format(s) will be most useful to experiments; for example, decimal time or hours, minutes, and seconds? NS

.3 What does sustained zero g do to wrist watches, or should all such personal time pieces be synchronized to the centralized time generator? OP

.4 What special problems are imposed on the time generator for its conversions to usable analog and digital values; for example, formats acceptable to computer inputs and outputs? PS

.5 What are the current state-of-the-art and the development and cost projections for these time generators through flight qualifications? PS

.6 What are the time base requirements of Space Medicine (Paragraph 1.1), Operations Experiments (Paragraph 1.3), and normal station-keeping; and how can all these requirements be consolidated with a central time generation system? 1-OE

1.2.1.2.6 Automatic Discriminators

.1 What design criteria and requirements are imposed upon automatic data discrimination? PS

.2 Do the discriminators perform in actual space operations as planned, or does man have to monitor these functions so that critical data are not lost in the filtration process? NS

.3 How can the discriminators be monitored, or how much interim storage is necessary to prevent irretrievable loss of valuable data. NS

.4 How may these automatic discriminators serve the requirements of Space Medicine (Paragraph 1.1), Operations Experiments (Paragraph 1.3), and normal house-keeping; and can these requirements be consolidated? 1-OE

.5 What are the zero-g, environmental load, logistic support, and maintenance requirements for these discriminators? PS

.6 What discriminators are available for the space vehicle tasks, and what modifications are necessary for the experiment technology required? PS

.7 What are the development and flight qualification problems, and respective costs for the discriminators? PS

1.2.1.3 Computer Programs

1.2.1.3.1 Onboard Programming

.1 What computer technology library facilities are necessary for onboard programming? PS

.2 What specialized peripheral scientific skills are required of the space vehicle computer programmer, or is programming a secondary skill of some onboard experimenter? 1-OE

.3 What ground-based computer facility communications are needed for the programmer? PS

.4 What onboard program checkout facilities are required? PS

1.2.1.3.2 Onboard Program Banks

.1 What onboard technologies require a program bank for their own work? PS

.2 What specific programs are required for each technology? PS

.3 What programs are common to more than one technology? PS

.4 What program identification means quickly show a normally nonusing technology the advantage of using all or part of any given program? PS

.5 What means most effectively allow the merger of one or more programs into a new special-purpose program? PS

.6 What specific techniques are used to set up an onboard program library, and how will it be stored? PS

.7 What specific techniques provide the best program access? NS

1.2.1.3.3 Earth Programming and Program Banks

.1 What kind of Earth programming group is needed to support the space vehicle? NS

.2 What special communication requirements are necessary to link space vehicle with Earth programming and banks? NS

.3 What emergency earth programming facilities can be put into action, and how long will this take? NS

.4 What priority system is required to set up a supplemental emergency programming facility? NS

.5 What determines the qualifications of the emergency programming personnel and facility, and how can they best be put into instant action? NS

.6 What special training is required to integrate the Earth and space crews if an emergency requires instant programming service? NS

.7 What methods and techniques integrate Earth program banks with the special programming group, particularly in the event of an emergency? NS

1.2.1.4 Temporary Data Storage

1.2.1.4.1 Investigator Written

.1 What kind of paper and writing instruments are required on the space vehicle? PS

.2 What kind of paper and writing instruments are required during EVA? PS

.3 What methods should be used to dispose of used paper? 1-LS-9

.4 What are the best methods to store paper records and notes, and to retrieve same when gravity forces are absent? PS

.5 What paper substitutes and processes might be considered for space vehicle use; for example, edible paper, plastic paper, inorganic or metallic sheets, chemical erasing, magnetic erasing, abrasion erasing? PS

.6 What kind of color writing instruments are desired? PS

.7 What kind of printed forms, data sheets, charts, graph papers, carbons, and engineering and scientific stationery items are required? PS

.8 What other stationery aids are required; for example, magnetic paper clips, magnetic staples, static or suction attraction of paper materials to desks, and how can a planimeter be made to work without gravity? PS

.9 What means are used to reproduce charts, graphs, etc? PS

1.2.1.4.2 Investigator Photographic

.1 What kinds of personal cameras, both still and movie, are required by the various investigators? PS

.2 What EVA cameras are required? PS

.3 What photographic developing and printing facilities are required, and how shall these be modified for zero-g operation? 1-OE-5

.4 What methods are required to store both unused and processed photographics, and what retrieval aids best assist the users? 1-OE-5

.5 What hazards to the environmental control system come from photographic material outgassing? 1-OE-5

.6 What peripheral accessories are required; such as lenses, exposure meters, special setups for microfilming, and microfilm quick access. 1-EE-1

.7 What disposal facilities are required for used photographics? 1-LS-9

.8 What photographic projection facilities are required? PS

1.2.1.4.3 Investigator Audio

.1 What kinds of miniature audio tape recorders are required for the investigators while monitoring experiments and while on active station duty? PS

.2 What special tape recorders may be required for EVA experiments or duty? PS

.3 What transcription facilities are required for permanent recording; for example, high-speed transmission to Earth for transcribing and digital transmission back to space vehicle for onboard printout? PS

.4 What advantages could be derived by numerous investigator plug-in points for recording on a central space vehicle tape recorder; for example, higher fidelity, parallel recording of real time during critical experiments? 1-OE-5

.5 What special training would optimize the effectiveness of the investigator versus the transcriber? PS

.6 What methods or facilities best make the transcribed audio tapes more accessible to the investigators and to the pertinent parts of the experiments in question? 1-OE-5

1.2.1.4.4 Computer Storage

.1 What conversion techniques allow all levels of experiment-generated data to be fully reduced or partially reduced for temporary storage? NS

.2 What computer-storage facilities are required for temporary data storage? NS

.3 What logistics advantages might show up in Earth storage of data, along with an upgraded communications link to allow same? NS

.4 What is the weight, power, environment, maintenance, and logistic support for the computer storage units? NS

.5 What is the current state-of-the-art, what are the development and cost projections for the storage units through flight qualification, and which of the current units are adaptable for flight? PS

.6 How can man control the possibility of storage overload by slight or major schedule shifts? PS

1.2.1.5 Permanent Data Storage

1.2.1.5.1 Magnetic Tape

.1 What magnetic-tape permanent storage units would be adaptable to space vehicle data permanent storage? PS

.2 What data-storage capacity would be required, and how much of this should be relegated to magnetic tape units? NS

.3 What is the maximum rate of storage for the magnetic tape units, and what is the most critical duty cycle for high storage rates? NS

.4 What buffer storage, temporary data storage, or Earth storage would be required to minimize the onboard magnetic tape storage units? PS

.5 What maximum access rate would be required for the magnetic tape units? NS

.6 What optimization factors in work-rest duty cycles, and experiment schedules provide the minimal peak loads on the magnetic tape storage units? NS

.7 What is the current state-of-the-art and what are the development and cost projections for the permanent magnetic tape storage subsystems through flight qualification? PS

1.2.1.5.2 Digital Printout

.1 What digital printout units would be adaptable to space vehicle permanent data storage? PS

.2 What are the state-of-the-art limitations in the printout speed and usable information density per unit printed area? PS

.3 What is the lowest limit of character size that can be rapid-access printed without loss of legibility? NS

.4 What magnification systems could be utilized to enlarge microminiaturized printing? 1-EE-1

.5 What comparative advantages could be shown for microminiature printout rolls, sheets, or cards? 1-EE-1

.6 What access techniques could be used for repetitive needs if the printouts were rolls, sheets, or cards? 1-EE-1

.7 What techniques would be best to provide duplicate or multiple copies? 1-EE-1

.8 What paper substitutes and processes might be advantageous for printout devices; for example, edible paper, combustible paper, reusable inorganic paper such as metallic foils, reusable plastics, magnetic erasing, or abrasion erasing? NS

.9 What are the maintenance problems for the printout units? NS

.10 What number of printout units would be required to take care of peak loads and/or downtime? PS

.11 What would be the development costs from new concept printers (or the type(s) selected) to the flight-qualified hardware stage? PS

1.2.1.5.3 Microfilming

.1 What microfilming equipment would be adaptable for the use of space vehicle permanent data storage? 1-EE-1

.2 What are the effects of zero g on microfilming equipment, and what revisions would have to be accomplished to make developing and processing film practical in space? 1-EE-1

.3 What micromicrofilming techniques and equipment would be adaptable for the space vehicle? NS

.4 What microfilm reading equipment would satisfy the overall system? NS

.5 What rapid microfilm information retrieval systems are available? PS

.6 What are the manned operational problems on the microfilming storage system? 1-EE-1

.7 What would be the development costs from the new concept microfilmer through flight qualification? PS

1.2.1.5.4 Magnetic Core

.1 What magnetic core systems would be adaptable for permanent or semipermanent data storage? NS

.2 What is the maximum storage density foreseeable in the future; for example, microminiature semiconductor storage? PS

.3 What are the comparative advantages and disadvantages of magnetic cores over other storage devices? PS

.4 What is the development cost to provide an optimum core storage unit for the space vehicle? PS

1.2.1.5.5 Microchemical Storage

.1 What microchemical techniques would provide potential application to space vehicle permanent data storage? PS

.2 What input-output devices would be available and adaptable to microchemical techniques? PS

.3 What are the comparative advantages and disadvantages of these techniques over other storage devices? NS

.4 What is the development cost of a microchemical storage system that would be competitive with other storage devices? PS

1.2.1.5.6 Investigator Storage

.1 What type and format of personal notebooks can be developed which will be conserving of volume for permanent data storage by space vehicle experimentors? PS

.2 What alternate techniques like Polaroid microfilming might replace notebooks and their accumulation of investigator data? 1-EE-1

.3 What type of rapidly erasable sheets could be developed to be used in conjunction with Polaroid-type microfilming? 1-EE-1

.4 What type of CRT short-time (1 day maximum) storage-displays could be developed which could reduce the quantity of paper storage and paper expendables (this to be used in conjunction with microfilming)? 1-EE-1

.5 What kind of personal quick-access microfilm reading equipment is adaptable for the experimentors? 1-EE-1

.6 What kind of work effectiveness would be gained or lost by the use of the specialized personal storage and retrieval devices? 1-EE-1

.7 What kind of personal training would be required in the use of specialized data storage and retrieval devices? PS

.8 What special problems arise in the use of personal data storage and retrieval devices in a zero-g environment? 1-EE-1

.9 What is the development cost of specialized personal data storage and retrieval devices? PS

1.2.1.5.7 Earth Storage

.1 What techniques are necessary to transmit prepared space vehicle data for permanent Earth storage NS

.2 What degree of digital onboard data processing would be advantageous prior to permanent Earth transmission and storage? NS

.3 What are the optimum techniques or methods for preparation of astronomical photographic data prior to permanent Earth transmission and storage? 1-EE-1

.4 What are the optimum techniques or methods for preparation of analog data prior to permanent Earth transmission and storage? 1-EE-1

.5 What are the resolution losses in photographic and/or analog data as transmitted to Earth for permanent storage and later back to the space vehicle. NS

.6 What are the logistic power penalities per bit of information for transmission back to the space vehicle? NS

.7 What are the logistic power penalities per square foot of analog data that is retransmitted back to the space vehicle? NS

.8 What are the development costs for the analog Earth storage preparation units? PS

.9 What are the development costs for the digital Earth storage preparation units? PS

.10 What are the development costs for the high resolution astronomical photographic Earth storage preparation units? PS

1.2.1.6 Data Collection

1.2.1.6.1 Hard Wires

.1 What kind of plug-in and multiple-shield wire systems are required to supply a linkage from the various data collection stations to the computer? NS

.2 What are the extreme ranges of signal level, so that shielding requirements may be established? NS

.3 What advantages would be established for multiple preamplifiers built into the terminal transmission points of each wire linkage subsystem? NS

.4 What are the tradeoff circumstances which may mandate that each experiment (planned for hard wire link to computer) carry its own preamplifier, so that station point-to-computer wiring may be standardized? NS

.5 What checkout equipment can provide assurance of wire-to-computer integrity from each plug-in station point? NS

.6 What are the development costs for each hard wire data collection subsystem? PS

1.2.1.6.2 Telemetry

.1 What multiple channel telemetry systems are adaptable to the space vehicle for experiment-to-computer linkage? OP

.2 What interferences to or from the telemetry link could be expected from other experiments or from the space vehicle operations? NS

.3 What maximum overall resolution or accuracy can be expected for an optimized telemetry system? NS

.4 What special requirements must be met for the telemetry transmitters, and what experiment-to-transmitter types of input need to be considered? PS

.5 What special requirements must be met for the telemetry receivers, and what receiver-to-computer types of input need to be considered? NS

.6 What are the development costs from prototype telemetry systems to specialized flight hardware? PS

1.2.1.6.3 Light Beam(s)

.1 What kind of visible beam transmission systems are applicable to space vehicle data collection systems? AC

.2 What are the most effective conversion units linking experiment to plug-in transmission points? AC

.3 What are the most effective conversion units linking beam terminus to computer input? AC

.4 What kind of guarded transmission pathways would prove most effective inside the space vehicle? AC

.5 What comparative advantages and disadvantages does light beam transmission have over other types of systems? PS

.6 What kind of maintenance problems would result from the rise of the light beam data transmission systems? AC

.7 What special restrictions would the experiments impose on the overall beam transmission? AC

.8 What are the development costs from prototype beam data transmission to flight-qualified hardware? PS

.9 What view-port light beam interference problems would arise from propulsion and waste expendable condensation on these surfaces. AC

1.2.1.6.4 Audio From Experimenter

.1 What kind of audio systems can be used to advantage in space vehicle data collection problems? NS

.2 What kind of microphone-to-transmission line units would be required, and what number of plug-ins would be necessary to cope with all experiment situations? NS

.3 What alternate configuration advantage can be shown with a miniature, portable audio experimentor hand-carried tape recorder; with a second channel simultaneous station time recording? NS

.4 What techniques can be used to retransmit the portable-generated audio tape to computer storage? Should this be at any one of multiple input points within the space vehicle or at the central computer location? NS

.5 What audio or digital code techniques can best process or retrieve the audio-taped information? NS

.6 What training techniques would serve to optimize the experimentor's role in the audio-tape data collection system? NS

.7 What are the development costs from prototype audio data collection systems to flight qualified hardware? PS

1.2.1.7 <u>Data Retrieval</u>

1.2.1.7.1 CRT Displays

.1 What kind of CRT display systems are adaptable to space vehicle data retrieval problems? 1-MM-1

.2 What advantages can be derived from color CRT for output data discrimination, particularly for analog curves? 1-MM-1

.3 What size CRT data retrieval displays (large screen for simultaneous group observance or personal small units) are required? 1-MM-1

.4 What maximum time display-storage requirement need be considered for the space vehicle? NS

.5 What photographic and/or microfilming techniques need be considered to preserve the displayed CRT information/data? 1-EE-1

.6 What mechanical or electronic overlay grids would be required for the CRT displays? 1-MM-1

.7 What short-time electronic storage banks can better link the CRT displays to the experimentor in his evaluation and processing of data? 1-EE-1

.8 What kind of audio recall system can be integrated with the CRT displays? PS

.9 What short-time storage audio-CRT storage banks can be recalled in mutual sequenced relationship for better linking the data retrieval displays to the experimentor? NS

.10 What kind of training programs can provide the experimentor with more effective use of the data CRT display retrieval system? NS

.11 What are the development costs from prototype CRT systems to flight-qualified hardware? PS

1.2.1.7.2 Digital Printout

.1 What automatic erasable digital printout units can be developed for space vehicle data retrieval systems? PS

.2 What role could microcharacter printers with associated CRT enlargers play in digital printout subsystems? 1-EE-1

.3 What kind of rapid access units are available for retrieving film or printed microcharacter data? PS

.4 What are the maintenance problems for the automatic erasable digital printout subsystems? PS

.5 What are the development costs for the automatic erasable digital printout subsystems from prototype to flight-qualified hardware? PS

1.2.1.7.3 Analog Plotting

.1 What analog plotting units are adaptable to space vehicle data retrieval subsystems? PS

.2 What is the maximum resolution, accuracy, and plotting speed for automatic point plotters? NS

.3 What is the maximum resolution, accuracy, and plotting speed for automatic line plotters? NS

.4 What are the equipment miniaturization limits, and what effects will zero g have on plotter operation? AC

.5 What possibilities exist for devising reusable paper or film for the analog plotters? NS

.6 What possibilities exist for color or symbol discrimination in miniaturized automatic plotters? NS

.7 What photographic or electro-optical enlargement units are adaptable to the miniaturized plotters? NS

.8 What copying techniques are adaptable to the photographic or electro-optical enlargement units; and what would zero-g do to their operation? NS

.9 What are the development costs for the analog plotter subsystems from prototype to flight-qualified hardware? PS

1.2.1.7.4 Microfilming

.1 What temporary microfilming process would have a comparative advantage over permanent microfilming? 1-EE-1

.2 What space vehicle disposal techniques are adaptable to consuming or reusing the unwanted microfilm records? 1-LS-9

.3 What are the manned operational problems on the microfilming retrieval system? 1-EE-1

.4 What developmental costs for a temporary microfilming process will be added to those of permanent microfilming (as covered in 1.2.1.5.3)? PS

1.2.1.8 Onboard Data Transmission

1.2.1.8.1 Experiment to Investigator

1.2.1.8.2 Experiment to Computer

1.2.1.8.3 Investigator to Computer

1.2.1.8.4 Experiment to Experiment

1.2.1.8.5 Investigator to Investigator

The critical issues relating to Paragraphs 1.2.1.8.1 through 1.2.1.8.5 are covered under Data Collection (1.2.1.6) and Data Retrieval (1.2.1.7).

1.2.1.9 EV Data Transmission

1.2.1.9.1 Experiment to Investigator

1.2.1.9.2 Experiment to Computer

1.2.1.9.3 Experiment to Experiment

The critical issues relating to Paragraphs 1.2.1.9.1 through 1.2.1.9.3 are covered elsewhere under Data Collection (1.2.1.6) and Data Retrieval (1.2.1.7).

1.2.2 ELECTRICAL POWER

1.2.2.1 Solar Cells

1.2.2.1.1 Rigid and Semirigid Arrays

.1	Deployment Mechanism Performance.	1-EE-2
.2	Array Dynamics During Deployment.	1-EE-2
.3	Thermal Gradients and Distortions as a Function of Orbit Position.	1-EE-2
.4	Measurement of Affects of Thermal Cycling and Thermal Shock on Substrates.	1-EE-2
.5	Cell/Module/Panel Replacement in Orbit.	1-OE-2
.6	Substrate Coatings (Backside) for Heat Rejection.	NS
.7	Effect of Shock Loads on Deployed Array.	1-EE-2
.8	Gimballing Mechanism Accuracy, Reliability, and Performance.	1-EE-2
.9	Slip Ring Design and Power Transfer.	1-EE-2
.10	Ground Handling, Checkout Equipment and Clean-Room Requirements.	NS

1.2.2.1.2 Cells

.1	Performance Evaluation of Silicon Cells.	1-EE-2
.2	Performance Evaluation of Thin Film CdS Cells.	1-EE-2
.3	Effects of Micrometeoroids on Cover Glasses.	1-EE-2

.4	Effects of Ionized Radiation on Cells, Adhesives, and Cover Glasses.	1-EE-2
.5	Interconnect Degradation and Reliability.	NS
.6	UV Reflective Coating Performance.	1-EE-2
.7	Cell Backside Photon Reflective Coating Performance.	NS
.8	Evaluation of Solders.	NS

1.2.2.1.3 Roll-Out Arrays

.1	Roll-out Deployment Mechanism Performance and Reliability for Multiple Cycling.	1-EE-2
.2	Membrane and Array Deployment Dynamics.	1-EE-2
.3	Determination of Damping and Means of Improving Damping Coefficient.	NS
.4	Thermal Gradients and Distortions as a Function of Orbit Position.	1-EE-2
.5	Effect of Shock Loads on Deployed Array.	1-EE-2
.6	Cell/Module Replacement in Orbit.	1-OE-2
.7	Cabling (Flat versus Round) Performance, Connections, and Replacement.	NS
.8	Ground Handling, Checkout Equipment and Clean Room Requirements.	NS
.9	Gimballing Mechanism Performance and Reliability.	1-EE-2
.10	Slip Ring Design and Power Transfer.	NS

1.2.2.2 <u>Battery</u>

1.2.2.2.1 Cells

.1	What is the effect of zero g on electrolyte concentrations in localized areas?	OP
.2	What is the effect of vacuum and ionized radiation on corrosion and leakage?	NS
.3	What are the fire and explosive hazards of cells in space?	NS

.4 What instrumentation is required in space for accurate determination of state of charge and discharge? NS

.5 What is the effect of space on battery cell seal design? OP

.6 How do the improved separator materials compare to state of art separators in space? OP

.7 What is the shelf and standby life of a cell in space? OP

1.2.2.2.2 Stacks/Modules

.1 How does space environment affect battery charge limit? OP

.2 What is the feasibility of operation in space of vented battery? NS

.3 What is the effect of space on individual cell and battery maintenance and replacement (electrically hot)? 1-OE-2

.4 How does space affect thermal control? OP

Passive?
Heat transport liquid loop?
Heat pipes?

.5 What is the rating and what factors influence the battery cycle life versus depth of discharge in space? PS

.6 What is the battery efficiency in space? OP

.7 What is the "exact" point of full battery charge in the space environment" OP

.8 What is the battery shelf-life in space? PS

1.2.2.3 Fuel Cells

.1 What is the effect of the space environment on cell performance? PS

.2 What is the effect of the space environment on long operating life? PS

.3 What is the effect of the space environment on fuel cell shelf life? PS

.4 What is the performance of auxiliary components in space? PS

.5 What is the effect of reactant impurities on cell operation in space? PS

.6 What is the effect of space on individual cell and module maintenance and replacement? PS

.7 What is the effect of ionizing radiation in space on fuel cell performance? PS

.8 What components and subsystems can be used in space for effective utilization of the fuel cell water byproduct? PS

.9 What is the performance of storable reactant fuel cells in orbit? PS

.10 What is the performance of regenerative fuel cells in space? PS

1.2.2.4 Brayton Cycle

1.2.2.4.1 Component

.1 Performance Test of Gas Bearings. PS

.2 Vibration and Shock Loadings on Turbine/Compressor/Alternator Performance. PS

.3 Heat Transfer Characteristics of Heat Transfer and Rejection Loops. PS

.4 Direct Gas Radiator Performance. PS

.5 Evaluation of High-Temperature Insulations. PS

1.2.2.4.2 Subsystem

.1 Control System Sensitivity to Transient Thermal and Electrical Loads. PS

.2 Dynamic Machinery Stability. PS

.3 Pressure Surging and Prevention. PS

.4 Maintenance and Replacement in Space. PS

.5 Startup and Shutdown Effects on System. PS

.6 Performance at Off-Design Operation. PS

.7 Thermal Gradients, Strains, and Creep Measurements of High-Temperature and High-Loaded Parts. PS

.8 Isolation of Adjacent Hot and Cold Running Components. PS

.9 Evaluation of Contaminate Buildup in Working Fluid and Heat Transport Loops. PS

.10 Gas Injection vs Alternator Motoring Startup. PS

1.2.2.5 Rankine Cycle

1.2.2.5.1 Component

.1 Boiling in Zero G. PS

.2 Condensing in Zero G. PS

.3 Evaluation of Working Fluids. PS

.4 Bearing Testing. PS

.5 Vibration and Shock Loadings on Turboalternator. PS

.6 Heat Transfer Characteristics of Heat Transfer and Rejection Loops. PS

.7 Improved Methods of Boiler Wetting. PS

.8 Effects of Fluid Leakage and Spills on Materials. PS

.9 Establishment of Clean-Up Procedures for Fluid Leakage. PS

1.2.2.5.2 Subsystem

.1 Control System Sensitivity to Transient Thermal and Electrical Loads. PS

.2 Stability of Dynamic Machinery. PS

.3 Erosion of Parts and Components. PS

.4 Corrosion and Buildup of Deposits. PS

.5 Fluid Slugging, Channeling, and Stratification. PS

.6 Fluid Injection and Startup in Orbit. PS

.7 Shutdown Procedures in Orbit. PS

.8 Collection of Fluids or Monitoring Where Fluid Is in Loop After Shutdown. PS

.9 Prevention of Fluid Freeze in Standby or Shutdown Condition. PS

.10 Breakdown and Contamination of Working Fluid. PS

.11 Paralleling of Subsystems and Load Sharing Control. PS

.12 Load Control Evaluation. PS

.13 Maintenance and Replacement. PS

.14 Thermal Gradients, Strains and Creep Measurements of High-Temperature and High-Loaded Parts. PS

1.2.2.6 Thermoelectric

.1 What is the effect of space environment on radiator coatings? PS

.2 What is the effect of zero g on fluid-flow channeling hot spots? PS

.3 What is the effect of space environment on converter materials? PS

.4 What is the effect of space environment on electrical insulation? PS

.5 What is the effect of space environment on thermal insulation? PS

.6 What is the effect of space environment on startup and shutdown? PS

.7 What is the effect of space environment on repair and replacement? PS

.8 What is the effect of launch environment on T/E material integrity? PS

.9 What is the effect of space environment on EM pump performance? PS

.10 What are performance characteristics of expansion compensator in space? PS

.11 How are contaminates removed from heat transport fluids in space? PS

.12 How are fluid levels measured in space? PS

.13 How are freeze-ups in fluid loops prevented during shutdown in space? PS

.14 How does the space environment affect improved T/E materials? PS

1.2.2.7 Thermionics

.1 What is stability of T/I materials in space environment? PS

.2 What is effect of zero g on fluid flow of out-of-pile diodes? PS

.3 What is effect of space environment on electrical insulation? PS

.4 What is effect of space environment on thermal insulation? PS

.5 What is effect of space environment on startup and shutdown? PS

.6 What is effect of space environment on repair and replacement? PS

.7 What are performance characteristics of expansion compensator in space? PS

.8 How are contaminantants eliminated or removed from fluids in space? PS

.9 How are freeze-ups in fluid loops prevented during shutdown in space? PS

.10 What are performance characteristics of cesium temperature control systems in space? PS

.11 What are performance characteristics of diode seals in space? PS

.12 What is the effect of cesium leakage in space on diode performance and adjacent components and wiring? PS

1.2.2.8 Nuclear Heat Sources (Reactors and Isotopes)

.1 What is effect of space environment on emergency operation? AC

.2 What is effect of high vacuum on control drum and heat dump door moving parts? AC

.3 What are the real radiation levels from nuclear heat sources in space? AC

.4 What is the effect of space environment on deployment booms? AC

.5 What is the effect of space environment on heat source replacement? AC

.6 What are the effects of deployed radiators or docked spacecraft on radiation levels due to scattering? AC

.7 What is the effect in space of liquid metal leakage from the primary heat transport loop? AC

.8 What is effect of zero g on fluid flow heat transfer characteristics and channeling in reactor loop? AC

.9 What is effect of space environment on primary loop pump and expansion compensator performance? AC

1.2.2.9 Radiators

1.2.2.9.1 Heat Transport Loop

.1 Fluid Flow Stability. PS

.2 Prevention of Fluid Freezing During Shutdown. PS

.3 Effects of Contaminates in Fluid. PS

.4 Evaluation of Fluids and Determination of Handbook Design Data for Operation in Space Environment. PS

.5 Pump Evaluation. PS

.6 Seal and Connector Performance. PS

.7 Evaluation of Flow Control and Sensing Instrumentation and Equipment. PS

.8 Evaluation of Feasibility of Component Repair. PS

.9 Determination of Parasitic Thermal Losses. PS

1.2.2.9.2 Heat Pipe

.1 Evaluation of Wicking Designs and Materials. PS

.2 Evaluation of Working Fluids. PS

.3 Determination of Thermal Resistance Coefficients Between Heat Pipe Plate and Member Due to Contact Pressure. PS

.4 Determination of Handbook Design Data for Operation in Space Environment. PS

1.2.2.9.3 Radiator

.1	Meteoroid Effects on Coatings.	PS
.2	Ionizing Radiation Effects on Coatings.	PS
.3	Application of Coatings in Space.	PS
.4	Prevention of Liquid Freezing.	PS
.5	Development of Modular Maintenance and Replacement.	PS
.6	Evaluation of Deployed Radiators.	PS
.7	Evaluation of Meteoroid Bumpers.	PS
.8	Evaluation of Radiator Materials.	PS
.9	Determination of Parasitic Thermal Losses.	PS

1.2.2.10 Power Conditioning

.1	What are the loads in space of the magnetic pull of the alternator rotor on bearings due to eccentricity in the winding gaps?	OP
.2	How does the space environment influence flash-over for high-voltage systems?	OP
.3	How do the load and thermal transients from operating in space affect load sharing and off-design operation?	OP
.4	How does the space environment affect the reliability of the components?	OP
.5	How does the space environment affect the performance of insulations?	OP
.6	What are the pattern and causes of electromagnetic interference generated by onboard equipment?	OP
.7	What are the performance characteristics of superconducting alternator and auxiliary support equipment in the space environment?	OP
.8	What is the optimum technique for maintenance and replacement of components?	OP
.9	What is the effect of the space environment on the overload rating of equipment?	OP

1.2.2.11 Power Distribution

.1 What is the effect of space environment on current and voltage rating of wires? OP

.2 What is the effect of higher operating voltages on subsystem performance? OP

.3 What is the best means of suppressing electromagnetic interference? OP

.4 What is the effect of the space environment on protection equipment (reverse current relays, circuit breakers, diodes, fuses)? OP

.5 What is the effect of the space environment on connectors, switches, and buses? OP

.6 What are the savings and penalties of single wire, paired wire, and shielded pair distribution in space? OP

.7 What are the combined affects of space environment, high temperature, corrosive fluids, and abrasion on wire insulation? OP

.8 How does flat cable compare to conventional cabling in the space environment? OP

.9 How does aluminum wiring compare to copper wiring in the spacecraft? OP

1.2.3 STABILIZATION AND CONTROL

1.2.3.1 Force/Moment Perturbation

1.2.3.1.1 Systematic

1.2.3.1.1.1 Atmospheric

.1 What are the magnitudes and profiles of aerodynamic force and moment acting on space vehicles of certain basic shapes (including fixed and gimballed solar panels)? 1-EE-3-2

1.2.3.1.1.5 Liquid Circulation

.1 What disturbances are generated by the circulation of large amounts of liquid as in EC/LS systems? 1-EE-3-2

1.2.3.1.2 Random

1.2.3.1.2.1 Crew Motion

.1 What are the magnitude and frequency characteristics of typical crew motion perturbations? 1-EE-3-2

1.2.3.1.2.3 Meteoroid

.1 What is the frequency of impact of meteoroids of different momenta? PS

1.2.3.1.2.4 Vibration

.1 What is the vibration environment generated by rotating devices (such as centrifuge and generators)? 1-EE-3-2

1.2.3.1.2.5 Docking

.1 What range of loads are generated during docking maneuvers? 1-EE-3-2

1.2.3.1.2.6 Tether

.1 What loads are generated between tethered units? PS

1.2.3.2 Sensors

1.2.3.2.1 Independent of Experiment Apparatus

1.2.3.2.1.1 Attitude

1.2.3.2.1.1.1 Gyro

.1 What is the nominal accuracy of attitude gyros in the operational space environment? 1 EE 3-1

.2 How does the zero-g environment affect the drift of inertial devices? 1 EE-3-1

.3 How does the space environment affect sensor reliability? 1 EE 3 1

1.2.3.2.1.1.2 Horizon Scanner

.1 What is the nominal accuracy of horizon scanners in the operational space environment? PS

1.2.3.2.1.2 Rate

1.2.3.2.1.2.1 Gyro

.1 What is the nominal accuracy of rate gyros in the operational space environment? 1 EE-3-1

.2 How does the zero-g environment affect the drift of inertial devices? 1 EE 3 1

1.2.3.2.1.3 Acceleration

.1 What is the nominal accuracy of accelerometers (transitional and rotational) in the operational space environment? PS

1.2.3.3 Control Force/Moment Generators

1.2.3.3.1 Propulsion Devices (Mass Expulsion)

1.2.3.3.1.1 Chemical

1.2.3.3.1.1.1 Liquid Systems

1.2.3.3.1.1.1.1 Propellant Storage and Management

1.2.3.3.1.1.1.1.1 Thermal Environment

.1	What are the temperature extremes of the surroundings?	OP
.2	What are the propellant temperature constraints?	OP
.3	Is the structure that supports the system designed to minimize thermal losses?	OP
.4	Is insulation required?	OP
.5	What kind of insulation can be used?	OP
.6	Is the structure compatible with the insulation?	OP
.7	Are heaters and thermostats required?	OP
.8	Which items require heating?	OP
.9	Are the items needing heat physically compatible with heater-thermostat installations?	OP
.10	What are the power limitations?	OP
.11	Are the system lines and components grouped to minimize power requirements?	OP
.12	What thermal control coating (α_s/ϵ) should be used?	OP
.13	What are the long term environmental effects on the thermal control coating?	OP

1.2.3.3.1.1.1.1.2 Tank Materials

.1 What are the material compatibility problems for the propellant tanks and associated equipment? OP

.2 How are these problems affected by:

a. Temperature? OP

b. Pressure? OP

c. Space Environment? (Such items as radiation and meteorite effects.) OP

d. Electrolytic action? OP

.3 What is the vibration environment and how does it affect the selection and design of propellant tankage and materials? OP

1.2.3.3.1.1.1.1.3 Propellant Utilization and Monitoring

.1 Are "off-mixture-ratio" operations possible and/or desirable? OP

.2 How can these operations be ascertained, and corrective action taken? OP

.3 What are the parameters that need to be monitored? OP

.4 What are the required instruments and the frequency of measurements? OP

.5 Is there any special support equipment (such as computers and programs) required? OP

1.2.3.3.1.1.1.2 Propellant Expulsion

1.2.3.3.1.1.1.2.1 Pressurization Systems

.1 What are the pressurization systems applicable for long duration, manned space missions? OP

.2 What are the thermal problems associated with these systems? OP

.3 What are the problems caused by the solution of pressurant gases into the propellants? OP

.4 What are the problems associated with the optimization of cycling techniques? OP

.5 What are the important parameters requiring monitoring to assure proper system operation? OP

.6 How are corrective actions determined and affected? OP

.7 What are the safety hazards and the governing control parameters? OP

1.2.3.3.1.1.1.2.2 Expulsion Devices

.1 What are the candidate devices for these applications? OP

.2 What are the material and environmental problems associated with the size of these devices? OP

.3 What are the cycling capabilities of these devices? OP

.4 How extensive is gas permeability and does it affect the system operation? OP

.5 What are the problems associated with malfunctions such as leakage and piston misalignment? OP

1.2.3.3.1.1.1.2.3 Gravity Effects

.1 How does the zero gravity environment affect the RCS propulsion system performance? OP

.2 What are the propellant settling and tank venting problems? OP

.3 What are the propellant orientation methods and devices? OP

.4 Are dielectrophoretic techniques effective and what are their limitations? OP

.5 How are the propellant resupply and heat transfer problems affected by low gravity fields? OP

1.2.3.3.1.1.4 Gaseous Propulsion Systems

1.2.3.3.1.1.4.1 Hot Gases

.1 What are the limitations of thrust, chamber pressure and impulse capabilities of the gaseous propulsion systems? PS

.2 What are the thermal and material problems associated with the generation and storage of hot gases used in RCS propulsion? PS

1.2.3.3.1.1.4.2 Heated Cryogen

.1 Are the vented cryogen gases adaptable to RCS propulsion applications? PS

.2 What are the power sources and required equipment for the utilization of the expanded pressurant and cryogen vented gases? PS

1.2.3.3.1.1.4.3 Stored Cold and Heated Gases

.1 Are main propulsion expanded ullage gases usable in RCS propulsion systems? PS

1.2.3.3.1.2 Electric

1.2.3.3.1.2.1 Ion Engines

.1 What are the areas of applicability for the micro-thrust, high ISP ion engines? NS

.2 What are the limitations for electric power requirements and associated power conditioning? NS

.3 What are the relative advantages and disadvantages of the contract and bombardment systems? NS

.4 Can thrust vector control provide for the stringent pointing accuracies needed for space telescopic experiments? NS

.5 What are the operational problems arising from electrode sputtering? NS

.6 What are the relative advantages of mercury and/or cesium propellants? NS

1.2.3.3.1.2.2 Plasma

1.2.3.3.1.2.2.1 Arc Jet

.1 Can plasma thrusters be operated without interfering with vehicle communications and experiments? NS

1.2.3.3.1.2.2.2 Magnetoplasmadynamic (MPD)

.1 What are the performance parameters of MPD thrusters in the hard vacuum of space? NS

1.2.3.3.1.2.2.3 MPD Solid Fueled

.1 Can solid MPD thrusters be adapted to use the solid biowastes? NS

1.2.3.3.1.2.3 Colloid

1.2.3.3.1.2.3.1 Needle

.1 What propellants can be best used with a colloid thruster for optimum performance? NS

.2 How well does charge neutralization of the colloid beam work to prevent vehicle charge buildup? NS

.3 What are the operational problems associated with the ejection of a colloid plume? NS

1.2.3.3.1.2.3.2 Thin Slit

.1 Can the thin slit thruster be made to operate with powdered fuel? NS

1.2.3.3.1.2.4 Resistojet

.1 What are the propellant systems most suitable for optimum use with the resistojet? NS

.2 What thrust levels are best suited for control and are these thrusters best used with CMG's? 1-EE-3-3

.3 Can expanded pressurant ullage gas be used as propellant? NS

.4 What are the material, thermal, and electrical problems? 1-EE-3-3

.5 How can the thruster design be improved to reduce electric power requirements? 1-EE-3-3

.6 How well does the thruster perform during off design operation? 1-EE-3-3

1.2.3.3.1.4 Other Propulsion Systems

1.2.3.3.1.4.1 Biowaste Resistojet

.1	What are the thruster material problems associated with the biowastes?	1-EE-3-3
.2	What are the life support recovery cycle biowaste compositions and mass production rates?	1-EE-3-3
.3	What are the interface storage and feed system design requirements?	1-EE-3-3
.4	To what extent will the contaminants in the plume degrade the vehicle surface and how may this be minimized?	1-EE-3-3
.5	What are the electric power requirements and controls?	1-EE-3-3

1.2.3.3.1.4.2 Radio-Isotope

.1	How does the radio isotope thruster performance compare with resistojets?	AC
.2	What are the candidate isotopes and their availability?	AC
.3	What are the safety problems associated with the nuclear radiation and what are the shielding penalties?	AC
.4	How does the design contend with the decay product helium pressure buildup?	AC
.5	Has the technology advanced sufficiently to warrant its use in a manned system?	AC

1.2.3.3.1.4.3 Subliming Solid

.1	What are the areas of applicability for space vehicle systems?	AC
.2	What are the advantages of valved versus valveless systems?	AC
.3	What are the optimum propellant formulations?	AC
.4	What are the thermal and electric power requirements?	AC
.5	How can the thruster's plume be prevented from condensing on the sensitive surfaces of the vehicle?	AC

1.2.3.3.2 Conservative Subsystems

1.2.3.3.2.1 Magnetic

.1 What magnetic control torque levels can be achieved for practical power levels? NS

1.2.3.3.2.3 Momentum Storage

.1 How does the zero-g environment influence the reliability of momentum storage subsystems? PS

1.2.3.4 Control System Design

1.2.3.4.1 Modeling

1.2.3.4.1.1 Torquers

1.2.3.4.1.1.3 Nonlinear Effects

.1 What are the nonlinear friction characteristics of CMG gimbals in the zero-g environment? OP

1.2.3.4.1.3 Flexible Body

1.2.3.4.1.3.1 Bending

.1 How can the body-bending characteristics of spacecraft be represented? NS

1.2.3.4.1.3.2 Torsion

.1 How can the torsion characteristics of spacecraft be represented? NS

1.2.3.4.1.3.3 Deformation due to Solar Heat

.1 How can long thin appendages (booms and panels) be modeled to account for deformations due to solar heating? NS

1.2.3.4.1.5 Isolation Systems

.1 How can isolation systems be modeled to account for the transmission of spacecraft perturbations to suspended experiment packages? NS

1.2.4 NAVIGATION AND GUIDANCE

1.2.4.1 Attitude and Position Sensors

1.2.4.1.1 Onboard Laser Ranging

.1 What navigation accuracy can be obtained using onboard laser ranging to ground based optical prisms? 1-EE-4-1

.2 What scheme is optimum for acquisition and tracking of the ground prism by the laser beam transmitter? 1-EE-4-1

.3 Do the prism areas derived theoretically provide the desired reflected signal strength? 1-EE-4-1

1.2.4.1.2 Strapdown Inertial Measurement Unit

.1 Can inflight shutdowns and restarts of the Inertial Measurement Unit (IMU) be accomplished without degrading the performance or shortening the life span? NS

.2 Can the sensing elements (gyros and accelerometers) be replaced and accurately calibrated onboard? 1-OE-2

.3 How does a near zero-g environment affect the drift and drift predictability of both the gyros and accelerometers? 1-EE-3-1

1.2.4.1.3 Microwave Sensors

1.2.4.1.3.1 Radar Altimeter

.1 Are the theoretical accuracies for altitude, velocity, and attitude measurements feasible for orbital navigation? NS

1.2.4.1.3.2 Navigation Satellite Ranging

.1 How accurately can ranging to a cooperative synchronous satellite be accomplished for Earth-orbital navigation? 1-EE-4-2

.2 What navigation accuracies are possible using navigation satellites as artificial spectroscopic binaries (satellite transmits continuous signal for Dopplar frequency measurements, discloses its orbital elements and provides standard time signals) to provide data for interplanetary navigation? 1-EE-4-2

1.2.4.1.3.3 Transponder Ranging

.1 How accurately can Earth orbital navigation be conducted using signal transmission on the spacecraft and reflection by transponders accurately located on Earth? 1-EE-4-1 1-EE-4-4

1.2.4.1.4 Optical Sensors

1.2.4.1.4.1 Star Trackers

.1 What are practical limits between field of view and accuracy requirements and what resolution of electronic scan devices are required to provide these limits? 1-EE-4-4

1.2.4.1.4.2 Sun Sensors

.1 Are angular accuracies better than 2 arc-seconds realizable? 1-EE-4-4

.2 Can same accuracy be obtained in and out of Earth's atmosphere? 1-EE-4-4

.3 Will proposed schemes for heat transfer from optics resolve thermal stability problems for high-accuracy sun sensors? 1-EE-4-4

1.2.4.1.4.3 Known Landmark Tracker

.1 What number of landmarks must be used to ensure four or more navigation updates during one orbit? 1-EE-4-3

.2 Does pattern recognition work reliably? 1-EE-4-3

1.2.4.1.4.4 Unknown Landmark Trackers

.1 Can man-in-the-loop significantly increase acquisition capability and reduce amount of computerized search logic required? 1-EE-4-3

.2 Are accuracy and reliability in unmanned applications suitable for accurate long term navigation required for orbit keeping and experiment support? 1-EE-4-3

1.2.4.2 Rendezvous and Docking Sensors

1.2.4.2.1 Laser Optical Radar

.1 Can automatic docking be performed with 10 centimeters in range accuracy and ±0.02-degree angular accuracies? OP

.2 Is acquisition at distances up to 200 nautical miles possible with the same laser unit, even at degraded accuracy? OP

1.2.4.3 Software

1.2.4.3.1 Digital Filters

.1 Will theoretically optimal, nondivergent filtering concepts work in the true random phenomena experienced in space? NS

1.2.5 COMMUNICATION SUBSYSTEMS

1.2.5.1 Emergency Communication Subsystems

1.2.5.1.1 Repair

.1 Repair of expandable antenna by EVA astronaut. This critical issue relates closely to those involved in the manual capabilities of the EVA astronaut. 1-OE 2

1.2.5.1.2 Auxiliary Emergency Systems

.1 Test of auxiliary emergency system. This experiment involves test of the ability of an EVA astronaut to establish communication with ground, using a "pocket" transmitter and deployable antenna. AC

1.2.5.2 Space Vehicle to and from Ground

1.2.5.2.1 Optical Methods: Cloud Cover

.1 Optical communication reliability (vehicle to ground). This calls for an extended program of transmission to ground under typical environmental conditions, including weather and Earth occlusion. A statistical analysis of the reliability and error rate of the link would be performed by ground-based computers. PS

1.2.5.3 Space Vehicle to/from Other Spacecraft

1.2.5.3.1 Secure Communication: 60 GHz RF Systems

.1 Test of a 60-GHz data transmission system (vehicle/module). Since this would be a system designed to be secure from ground, the tests would involve (1) capability of the system as a data transmission system, and (2) tests of the security of the system from ground interception. AC

1.2.5.3.2 Communication with EVA Astronauts

.1 Test of closing velocity indicator for an EVA astronaut returning to the mother ship. (For returns from fairly remote EVA, the unaided velocity perception of the astronaut may be poor, with danger of a collision with the mother ship.) Two modes would be tested. In one, the closing velocity of the astronaut would be monitored by radar on the vehicle, and the astronaut would be coached to a safe landing. In the other, the astronaut would be provided with a small, self-contained Doppler radar, so that he could monitor his velocity without assistance from the vehicle. AC

.2 Tests of a system to maintain communication with an EVA astronaut when occluded. The system would require deployable relays, and the tests would provide information for optimum design of these relays. AC

1.2.5.4 Space Station to and from Deep Space Vehicles

1.2.5.4.1 Optical Systems

.1 Optical communication reliability (vehicle to deep space vehicle). 1-EE-5
An extended program of transmission from the DSV to the manned vehicle would be undertaken using a prearranged coded message. The error rate and signal-to-noise ratio would be measured under typical operating conditions, which would include effects caused by relative vehicle velocities, pointing errors, and delay in acquisition after occlusion.

1.3 OPERATIONS EXPERIMENTS

1.3.1 SPACE LOGISTICS AND RESUPPLY

1.3.1.1 Interfaces

What are the design requirements for the following space vehicle logistics interfaces to accomplish effective manned operations? The devices and their requirements are:

1.3.1.1.1 Docking Ports

.1 Docking ports for cluster and large modules as well as small man-transfer units considering positioning guidance, restraint, (latching or other), safety. 1-OE-1-1

1.3.1.1.2 Hatches and Airlocks

.1 Hatches and airlocks to satisfy speed, gas dump, size compatibility with various elements to be transferred, seal protection, safety. 1-OE-1-1

1.3.1.1.4 Proximity Restraints and Positioning

.1 Proximity restraints and position controls, such as tie downs, clamps, cables, booms, and Velcro. 1-OE-1-1

1.3.1.1.5 Umbilicals: Fluids, Electrical

.1 Umbilical design to accomplish safe liquid, gas, or power transfers. Disconnect design, remote operations of high pressure systems, purging, and dumping. 1-OE-1-1

1.3.1.1.6 Transfer Tunnels: Supplies, Guides, Men

.1 Transfer tunnels for solids, men, supplies and their use in proximity for long distance operations. 1-OE-1-1

.2 Transfer cables and guides for proximity and long distance movement of elements. 1-OE-1-1

1.3.1.1.7 Operations Staging

.1 Staging and storage areas, either EVA or IVA. Design requirements to make available various aids, consumables, and checkout. What distances and locations are most suitable for these areas? NS

1.3.1.2 Operations

What is man's capability to support logistics operations in support of the space vehicle activities? What proximity or remote control operations can make the best use of this capability? The operations considered are:

1.3.1.2.1 Acquisition: Manned, Remote

.1 What are the problems of acquisition of various units in the space vehicle's proximity or in a compatible orbit (satellite)? 1-OE-4

.2 What is man's capability to steer close to unit and effect a "hookup" in a safe and nondamaging manner? 1-OE-4

.3 What are the tools and aids that best support these operations? 1-OE-4

1.3.1.2.2 Restraint/Positioning: Manned, Remote (See 1.3.1.2.3)

1.3.1.2.3 Docking: Manned, Remote

.1 (a) Restraint and positioning of units or satellite and (b) docking to compatible units. What are the best procedures and designs? 1-OE-4

1.3.1.2.4 Cargo Transfer: Manned, Remote (See 1.3.1.2.5)

1.3.1.2.5 Storage/Resupply: Manned, Remote

.1 Cargo transfer and storage operations in space or IVA. What are the various container shapes, location, and storage procedures best suited for space vehicle efficiency and flexibility? 1-OE-1-1

1.3.1.2.6 Disposal

.1 What techniques are best applicable to a safe disposal of used items? Different orbits? Deorbiting? Controlled Captivity? 1-OE-1-1

1.3.1.3 Data Capsules

.1 What is man's capability to handle data capsules of various designs and sizes? Consider: AC

(a) Storage
(b) Loading techniques
(c) Transfer from storage to launcher
(d) Launch operations safety.

1.3.1.4 Personnel

What are the various mobility aids required to support man's logistic operations, and what are their peculiar design requirements for maintaining efficiency and flexibility? The following items are considered:

1.3.1.4.1 Mobility Aids

.1 Passive mobility aids in EVA and IVA such as body restraints, hand holds, design and location of rails and cables, use of Velcro, magnetic devices, or other restraints allowing maximum body usage. 1-MM-2

.2 Mechanical devices which man can use to move and still maintain some degree of body restraint in order to exert force. Consider articulated and extendible devices. 1-MM-2

.3 (a) Powered devices in IVA operations to transfer man or cargo and supplies to various attached modules. Consider rails, cables, and conveyor systems. 1-MM-2

(b) Powered devices in EVA operations to move man to the work area or element. Consider backpacks, taxi modules, and hand-held thrusters. What are the best design features for these units in terms of mobility, station keeping, restraint devices, storage areas, and operational radii?

.4 Remote control units to (a) deploy and position transfer aids, such as rails or cables, (b) acquire and restrain satellites or experimental modules, and (c) unload and transfer cargo. 1-MM-2

1.3.1.4.2 Operations Support

.1 What are the requirements and design features to allow man to conduct flexible and meaningful operations activities? Consider (a) rest and resupply shelters, their location, frequency, size and design; and (b) operations staging areas, especially in overlapping or consecutive operations. PS

1.3.1.5 Rescue/Emergency

1.3.1.5.1 Monitoring

.1 What is the effectiveness of space emergency monitoring aids using contact between the base station and the operation through (a) visual means, (b) verbal contact, and (c) automated position and status sensors? 1-OE-1-2

1.3.1.5.2 Emergency

.1 What are the emergency shelters, their location, and frequency in order to allow for partial or total emergencies? Consider (a) airlocks, (b) tunnels and holds, (c) emergency supplies, and (d) life support systems. 1-OE-1-2

1.3.1.5.4 Manned Rescue

.1 What is man's capability to effect rescue? Consider (a) mobility and time to reach critical area using the various mobility aids previously described, (b) acquisition and restraints on man or manned/unmanned modules, (c) use of emergency tools to reach man, and (d) first aid if required. 1-OE-1-2

.2 What is man's capability to conduct rescue operations during space vehicle emergencies? What are the tools and aids required to conduct these operations by man or by remote control, including ground control? 1-OE-1-2

1.3.1.5.5 Remote Control

.1 What remote control units are required for rescue and emergency situations, such as fire or other hazards preventing proximity approach? Consider (a) monitoring aids required to maintain contact under emergency conditions and over long distances. (b) various IVA and EVA mobility aids, and (c) emergency return units (individual or multipersonnel). 1-OE-1-2

1.3.1.5.6 Ejectable Capsules

.1 What is the effectiveness of ejectable capsules to safely remove man either from the space vehicle or from operational modules? What are the compatible emergency return vehicles to be used? Consider: (a) open heat shield devices either rigid, extendable, or inflatable, (b) small capsules and clamshells, and (c) controllable reentry modules. AC

1.3.2 MAINTENANCE, REPAIR, AND RETROFIT

(Note: A parallel structure exists in this area. Operational aspects are developed in Charts 1-72, and 1-79 through 1-82, while the functional aspects and their relation to man's capabilities are found in Charts 1-88 through 1-90. The critical issues listed below are developed only with respect to the latter, the functional considerations.)

1.3.2.1 Effectiveness of Man's Sensory Perceptions

1.3.2.1.1 Visual

What is man's capability in various lighting, contrasts, and field-of-view constraints to visually sense:

.1 Relative and absolute distances between objects? 1-BR-1

.2 Discoloration, contamination, or wear in various surfaces such as mirrors, thermal paints, covers, and cables? 1-OE-2

.3 Cracks and scratches? 1-OE-2

.4 Leaks or condensation of liquids and gases? 1-OE-2

.5 Loose hardware, debris, and dust? 1-OE-2

.6 Smoke and fire? PS

1.3.2.1.2 Smell

.1 What is man's capability to use smells of various fluids including hot area (or fire) emissions to provide leakage, operational, or malfunction sensing? 1-OE-2

1.3.2.1.3 Touch

What is man's capability in shirtsleeve, IVA, and EVA conditions to use his touch to sense:

.1 Surface finishes and deterioration or defects? 1-OE-2

.2 Temperatures? 1-OE-2

.3 Moisture, condensates, or deposits on various surfaces? 1-OE-2

.4 Pressure leaks? 1-OE-2

1.3.2.1.4 Sound

What is man's capability under shirtsleeve, IVA, and EVA conditions to use his hearing ability to sense:

.1 Fluid leaks? 1-OE-2

.2 Malfunctioning or wear signs in mechanisms? 1-OE-2

.3 Impact or meteoroids or other loose objects? 1-OE-2

.4 Valve or moving component operation? 1-OE-2

1.3.2.2 Limitations of Accessibility and Mobility on Man

1.3.2.2.1 Hand Manipulation

.1 What is man's capability, using free hands and various handwear (IVA, EVA), to handle small items (such as washers, screws, and seals) or to reach into small areas (such as when removing "O" ring seals and pins)? 1-OE-2

1.3.2.2.2 Body Mobility while Restrained

What are man's space constrained accessibility limits while in shirtsleeve, IVA, or EVA conditions for the following:

.1 Hand reach and motion capability? 1-OE-2

.2 Minimum space requirements for torso or two hands? 1-OE-2

.3 Full body minimum space allocation? 1-OE-2

.4 Access to hard-to-reach areas? 1-OE-2

1.3.2.2.3 Group Effort Capabilities

.1 What is man's capability, on a noninterference basis, to work in proximity with others while using various IVA and EVA suits or backpacks (motion air, etc.)? 1-OE-2

1.3.2.2.4 Unrestrained Mobility Aids

.1 What motion aids are needed to allow man in IVA or EVA conditions to reach the space vehicle critical areas: 1-MM-2

(a) Passive locomotion aids, such as handrails, cables, and handholds?

(b) Powered aids, such as backpacks (scooters), hand-held thrusters, small transfer modules (taxis), and large transfer modules (buses)?

(c) Mechanical aids, such as articulated arms, extendible arms, and booms?

1.3.2.3 Allocations of Time and Energy for Operations

.1 What are the time and energy limits on man's direct operations in shirtsleeve, IVA, and EVA conditions? NS

(a) Hands operations

(1) Squeezing
(2) Pushing and pulling
(3) Twisting
(4) Impact

(b) Body operations

(1) Transfer

.2 What is man's capability in shirtsleeve, IVA, or EVA conditions to accomplish a coordinated task, using various tools and operations? For example, time and energy allocation to move to a solar panel (EVA); inspect panel; disconnect, remove and replace it with a new panel; reconnect; checkout; dispose of the damaged panel; and return to base. 1-OE-2

1.3.2.4 Development Tools and Aids

.1 What is man's capability in shirtsleeve, IVA, or EVA conditions to make use of the following tools? Consider size and shape, counterforce application, body restraints and supports, space and access limitations, debris, residual collection, retention of loose items, and safety requirements. 1-OE-2

(a) Hand-operated tools

torquing, squeezing, sawing, hammering

(b) Hand-held power tools

(c) Welders

fluid lines, automatic welding
structural, manual, or automatic control
torch cutting

(d) Brazing

fluid lines

(e) Soldering

electronic/electromechanical

(f) Bonding

structural or nonstructural assembly and positioning

(g) Foam-in-place dispensers

repair of pressure shells

(h) Augmented reach tools

proximity tools, using mechanical extensions and controls

.2 What are the required aids to allow man to perform the required operations? 1-OE-2

(a) Body restraints and positioning aids

(b) Components transfer aids

rails, cables, powered motion aids
bumpers, restraints

(c) Alignment aids

optical instruments
distance measurements
preloads in structure, springs

(d) Sensors

leak detection
surface contamination

properties, abrasion, oxidation, cracks
heat
debris and dust
moisture/condensates
gases
cracks
insulation systems degradation

.3 How is man's capability improved by artificial gravity, specifically when doing complex operations on small elements and components? 1-OE-2

1.3.2.5 Control of Operations Hazards and Residuals

.1 What are the safety requirements in shirtsleeve, IVA, or EVA conditions? NS

(a) Mechanical and Structural hazards

Control of debris and dust
Power tools, welders
Preloaded cables and springs
Restraint of large elements

(b) Fluid Emissions

Line breaks or leaks
Residuals
Bonding operations
Welding, brazing, soldering

.2 What are the disposal techniques required for: 1-LS-9

(a) Housekeeping debris and dust
(b) Clean-up hardware
(c) Damaged or discarded components

1.3.2.6 Operations Planning

.1 How do space vehicle activities affect the planning and timely execution of maintenance, repair, and retrofit jobs? Consider all interfaces with other systems and operations, such as: NS

(a) Space vehicle attitude disturbances which affect ongoing attitude-critical experiments or operations

(b) Effluent control while operations are in proximity

(c) Hot-gas (rocket motor) or cold-gas exhaust interference

(d) Safety limitations on operational capability due to high-pressure systems, dangerous fluids, electrical-ordnance systems, and high-preload mechanisms or structures.

1.3.3 ASSEMBLY AND DEPLOYMENT

1.3.3.1 Assembly

1.3.3.1.1 Positioning

1.3.3.1.1.1 Acquisition: Mobility, Restraints

.1 What is man's capability to move from one element to another to attain control of the unit to be assembled, using various mobility aids? 1-OE-3

.2 What is the relative effectiveness of manned proximity controls (mechanical arms) and remote control operations during each phase of the assembly process? 1-OE-3

1.3.3.1.1.2 Alignment: Transfer, Adjustment

.1 What is man's capability to accurately and efficiently attach various guides, restraints, and safety devices on the module or elements in an accurate, untangled fashion? 1-OE-3

.2 What are the effectiveness and operation control advantages of mechanically restrained (rigid, straps, cables, pins, guides) vs. fly-in techniques for: 1-OE-3

(a) Proximity positioning
(b) Initial alignment

Linear
Rotational
Angular

(c) Final adjustment

.3 What tools and devices are best suited for proximity and fine alignment of modules to be joined? 1-OE-3

Rigid elements
Flexible elements
Pins and guides

1.3.3.1.2 Attachment

1.3.3.1.2.1 Mechanical

.1 What are the mechanical locking/assembly techniques best suited for man aided assembly operations in space, especially in non-permanent assembly requirements? Consider: 1-OE-3

Size/weight
Ease and reliability
Strength
Manual vs. augmented or remote control operation

1.3.3.1.2.2 Structural

.1 What are the structural assembly techniques best suited for man-aided assembly operations in space, especially in permanent or semi-permanent assembly requirements? Consider: 1-OE-3

Various fastener types
Bonding
Welding

1.3.3.1.2.3 Umbilicals

.1 What are the most suitable designs for umbilical connectors required between the modules? Consider: NS

Fluid high pressure
      low pressure
Electrical connectors

.2 What are the most suitable access and transfer devices between the two modules, especially considering pressure controlled or common atmosphere requirements? Consider: NS

Size requirements (single unit, many modules)
Seal design in nonpermanent joints
Welding of transfer tunnels for permanency
Bonding seals

1.3.3.1.2.4 Insulation/Protective Covers

.1 What are the most suitable designs and attachment techniques for intermodule insulation, protective covers, and transfer aids required after module assembly? Consider: NS

Fasteners
Bonding
Velcro
Storage

1.3.3.2 <u>Deployment</u>

1.3.3.2.1 Erectable

.1 What are the most effective designs for erectable structures (element assembly) in order to build up various booms, trusses, shapes (antennas, panels, etc.) in space? Consider: 1-OE-3

Fastening
Restraints, handling ease
Alignment

1.3.3.2.2 Mechanically Deployed

.1 What are the most effective designs for mechanically deployed structures? NS

.2 What simplifications and advantages can be added by manned operations? Consider: 1-OE-3

Folded bulk
Deployment aids and power sources
Safety (preloaded devices)
Designs using translation, rotation,
Articulations (scissors, accordions)

1.3.3.2.3 Expandables

.1 What are the most effective designs for expandable structures using various internally pressurized elements applicable to the design of auxiliary structures such as crew transfer tunnels, air locks, maintenance hangars, experiment bays, or living quarters? Consider: 1-OE-3 1-EE-2

(a) Packaging requirements/techniques

(b) Packaged bulk

(c) Deployment aids—pressure/techniques

(d) Rigidization requirements/techniques

(e) Man rated requirements

(f) Retraction requirements/techniques

1.3.3.2.4 Interfaces

.1 In addition to the specific design features what are the relative merits of the three deployment methods outlined above? Consider: 1-OE-3

(a) Deployed size limitation due to manned constraints, specifically for erection type elements

(b) Stability in space considering thermal deflections and operational loads

(c) Safety considering rigidity of the structure, damage susceptibility failure mode

(d) Reusability and adaptation to various requirements during the life span of the space vehicle (commonality)

(e) Aids for manned inspection transfers

(f) Flexibility for modification

(g) Ease of disposal or disassembly

(h) Ability to support umbilicals and other interfaces

(i) Alignment capability and accuracy; ease of alignment

(j) What is their adaptability to direct or remote control operations during buildup, alignment and activation?

1.3.4 MODULE OPERATIONS

1.3.4.2 <u>Control and Guidance</u>

1.3.4.2.1 Inertial Orientation and Rate Stabilization

.1 To what accuracy can the inertial orientation of the unmanned module be controlled during brief and extneded periods of time? 1-OE-4

.2 To what extent can the module be rate stabilized during brief and extended periods of time? 1-OE-4

1.3.4.2.2 Instrument Inertial Pointing and Tracking

.1 What pointing accuracy can be maintained by an instrument on the module while viewing a target fixed in inertial space? SA

.2 With what accuracy can an instrument on the module track CN,EO

(a) a target on Earth?
(b) the vehicle?

1.3.4.2.3 Disturbances of Man (EVA)

.1 What disturbances of the module are caused by man in an EVA mode? 1-OE-4

1.3.4.2.4 Launching and Docking Dynamics

.1 What disturbances are exerted on the module due to launching and docking? 1-OE-4

1.3.4.2.5 Maintenance of Vehicle/Module Separation

.1 What minimum drift rates of the detached module, relative to the space vehicle, can be achieved? 1-OE-4

.2 What is the optimum separation distance between module and space vehicle? 1-OE-4

1.3.4.2.6 Rendezvous and Orbit Keeping

.1 How precisely can the separation distance between module and vehicle be determined? 1-OE-4

1.3.5 VEHICLE SUPPORT OPERATIONS

1.3.5.3 Control and Guidance

1.3.5.3.1 Inertial Orientation and Rate Stabilization

.1 To what accuracy can the inertial orientation of the manned vehicle be controlled during brief and extended periods of time? 1-OE-5

.2 To what extent can the vehicle be rate stabilized during brief and extended periods of time? 1-OE-5

1.3.5.3.2 Instrument Inertial Pointing and Tracking

.1 What pointing accuracy can be maintained by an instrument on the vehicle while viewing a target fixed in inertial space? 1-OE-4

1.3.5.3.3 Translational Tracking of Module

.1 With what accuracy can an instrument on the vehicle track 1-OE-4

(a) a target on Earth?
(b) the module?

1.3.5.3.4 Monitoring Module Operations

.1 How efficiently can man guide and control himself while traveling between the vehicle and the remote module for close monitoring? 1-OE-4

.2 How far can man safely venture from the space vehicle for monitoring and other functions? 1-OE-4

APPENDIX C

RESEARCH CLUSTERS

MANNED SPACEFLIGHT CAPABILITY

C-1

INTRODUCTION
APPENDIX C

This Appendix presents the Research Cluster Descriptions prepared by the study team of the Earth Orbital Experiment Program and Requirements Study. Each description, in general, consists of (1) a synopsis; (2) a list (by number and title) of the critical issues addressed by the Research Cluster Description. The identification of these Research Cluster Descriptions by number and title is given in Table C-1.

Table C-1

RESEARCH CLUSTERS

MANNED SPACEFLIGHT CAPABILITY

Cluster No.	Title
BIOMEDICINE	
1-BM-4*	Effects of Weightlessness on Circulatory Function
1-BM-5	Radiation, Toxicology, and Medical Problems
1-BM-6	Effects of Weightlessness on Stress Response
1-BM-7	Effects of Weightlessness on the Nervous System
1-BM-8	Effects of Weightlessness on Gastro-intestinal Function
1-BM-10	Body Fluid Analysis
1-BM-12	Studies on Instrumented Animals
1-BM-13	Effects of Weightlessness on Pulmonary Function
1-BM-14	Effects of Weightlessness on Metabolism
1-BM-15	Centrifuge Studies
BEHAVIORAL RESEARCH	
1-BR-1	Sensory, Psychomotor, and Cognitive Behavior (5 parts)
1-BR-1-1	Visual Experiment
1-BR-1-2	Behavior Effects of Acoustic Environment
1-BR-1-3	Psychomotor
1-BR-1-4	Cognitive Capability
1-BR-1-5	Orientation
1-BR-2	Group Dynamics and Personal Adjustment

---

*Missing numbers were assigned to clusters that were later combined with others or eliminated.

Cluster No.	Title
1-BR-3	Complex Task Behavior
1-BR-4	Skills Retention
1-BR-6	Performance Measurement

MAN-MACHINE RESEARCH

1-MM-1	Controls and Displays
1-MM-2	Locomotion and Restraint
1-MM-3	Habitability
1-MM-4	Work/Rest/Sleep Cycles
1-MM-5	Performance Aids

LIFE SUPPORT AND PROTECTIVE SYSTEMS

1-LS-1	Phase Change and Thermal Processes
1-LS-2	Material Transport Processes
1-LS-3	Atmosphere Supply Processes
1-LS-4	Water Management
1-LS-5	Water Electrolysis
1-LS-6	Food Management and Processes
1-LS-7	Atmosphere Purification Methods
1-LS-8	Life Support Monitoring and Control
1-LS-9	Waste Management
1-LS-10	Heat Transport Equipment
1-LS-11	Crew Equipment and Protective Systems
1-LS-12	Life Support System Maintenance and Repair

ENGINEERING EXPERIMENTS

1-EE-1	Data Management
1-EE-2	Structures
1-EE-3	Stabilization and Control (3 parts)

Cluster No.	Title
1-EE-3-1	Drift Measurement of Gyroscopic Attitude Controls
1-EE-3-2	Disturbance Torque Measurements
1-EE-3-3	Biowaste Electric Propulsion
1-EE-4	Navigation and Guidance (4 parts)
1-EE-4-1	Onboard Laser Ranging
1-EE-4-2	Interplanetary or Translunar Navigation By Spectroscopic Binary Satellite
1-EE-4-3	Landmark Tracker Orbital Navigation
1-EE-4-4	Navigation/Subsystem Candidate Evaluation
1-EE-5	Communications

OPERATIONS EXPERIMENTS

1-OE-1	Logistics and Resupply (2 parts)
1-OE-1-1	Space Logistics and Resupply
1-OE-1-2	Emergency and Rescue Operations
1-OE-2	Maintenance, Repair and Retrofit
1-OE-3	Assembly and Deployment
1-OE-4	Module Operations
1-OE-5	Vehicle Support Operations

SPACE BIOLOGY

VERTEBRATES

2-VB-1	Preliminary Investigations of Biological Processes, Using Primates and Small Vertebrates
2-VB-2	Intermediate Investigations of Biological Processes, Using Primates and Small Vertebrates
2-VB-3	Advanced Investigations of Biological Processes, Using Primates and Small Vertebrates

Cluster No.	Title
INVERTEBRATES	
2-IN-1	Preliminary Investigations of Biological Processes, Using Invertebrates
2-IN-2	Intermediate Investigations of Biological Processes, Using Invertebrates
2-IN-3	Advanced Investigations of Biological Processes, Using Invertebrates
PROTISTS AND TISSUE CULTURES	
2-P/T-1	Preliminary Investigations of Biological Processes, Using Unicellular Specimens (protists and tissue cultures)
2-P/T-2	Intermediate Investigations of Biological Processes, Using Unicellular Specimens (protists and tissue cultures)
2-P/T-3	Advanced Investigations of Biological Processes, Using Unicellular Specimens (protists and tissue cultures)
PLANTS	
2-PL-1	Preliminary Investigations of Biological Processes, Using Plants
2-PL-2	Intermediate Investigations of Biological Processes, Using Plants
2-PL-3	Advanced Investigations of Biological Processes, Using Plants
SPACE ASTRONOMY	
OPTICAL	
3-OW	Optical Structure of Small Extended Sources
3-OB	High-Resolution Planetary Optical Imagery
3-OS	Optical (Faint Threshold) Surveys
3-OP	High Precision Stellar Photometry
3-SO	Optical Studies of the Solar Photosphere and Chromosphere

Cluster No.	Title
X-RAY	
3-XR	Precise Location, Size, and Structure of Known Discrete X-ray Sources, and Existence of Additional Unknown Sources
LOW FREQUENCY RADIO	
3-LF	Location and Properties of Discrete LF Radio Sources, and Structure and Properties of Diffuse Sources
SPACE PHYSICS	
PHYSICS AND CHEMISTRY LABORATORY	
4-P/C-1	Effect of the Space Environment on Chemical Reactions
4-P/C-2	Shape and Stability of Liquid-Vapor Interfaces
4-P/C-3	Boiling and Convective Heat Transfer in Zero-G
4-P/C-4	Effect of Zero-Gravity on the Production of Controlled Density Materials
4-P/C-5	Effect of Electric and Magnetic Fields on Materials
4-P/C-6	The Use of Zero-Gravity to Produce Materials Having Superior Physical Characteristics
4-P/C-7	Improvements of Materials by Levitation Melting
4-P/C-8	Effect of Zero-Gravity on the Production of Films and Foils
4-P/C-9	Effects of Zero-G on Liquid Releases, Size Distribution of Liquid Drops
4-P/C-10	Capillary Flow in Zero-G
4-P/C-11	Behavior of Superfluids in the Weightless State
PLASMA PHYSICS LABORATORY	
4-PP-1	Spacecraft Environment Interaction
4-PP-2	Energetic Particle Dynamics in the Magnetosphere (3 parts)

Cluster No.	Title
4-PP-2-1	Use of Alkali Metal Clouds as a Space Diagnostic
4-PP-2-2	Use of Electron Beams as a Space Diagnostic
4-PP-2-3	VLF Wave Propagation
4-PP-3	Thermal Plasma in the Ionosphere and Magnetosphere (3 parts)
4-PP-3-1	(Essentially the same as 4-PP-2-1)
4-PP-3-2	(Essentially the same as 4-PP-2-3)
4-PP-3-3	RF Plasma Resonance Studies
4-PP-4	Auroral Processes (3 parts)
4-PP-4-1	(Essentially the same as 4-PP-2-1)
4-PP-4-2	(Essentially the same as 4-PP-2-2)
4-PP-4-3	(Essentially the same as 4-PP-2-3)

COSMIC RAY LABORATORY

4-CR-1	Charge and Energy Spectra of Cosmic Ray Nuclear Component
4-CR-2	Energy Spectrum of High-Energy Primary Electrons and Positrons
4-CR-3	Energy Spectrum and Spatial Distribution of Primary Gamma Rays
4-CR-4	Long-Lived Heavy Isotopes in Cosmic Rays
4-CR-5	Antinuclei in Cosmic Rays
4-CR-6	Quarks (Stable Fractionally Charged Particles) in Cosmic Rays
4-CR-7	Unknown Particles in Cosmic Rays
4-CR-8	Characteristics of Albedo Particles Above 100 MeV
4-CR-9	Nucleon-Nucleon Cross-Sections at High Energies
4-CR-10	Spallation Cross-Sections at High Energies

Cluster No.	Title
COMMUNICATIONS AND NAVIGATION	
NOISE	
5-N-1	Terrestrial Noise Measurements
5-N-2	Noise Source Identification
PROPAGATION	
5-P-1	Ionospheric Propagation Measurements
5-P-2	Tropospheric Propagation Measurements
5-P-3	Plasma Propagation Measurements
5-P-4	Multipath Measurements
TEST FACILITIES	
5-TF-1	Space Deployment and Calibration
5-TF-2	Demonstration and Test
COMMUNICATIONS SYSTEMS	
5-CS-1	MM Wave Demonstration
5-CS-2	Optical Frequency Demonstration
NAVIGATION SYSTEMS	
5-NS-1	Satellite Navigation Techniques for Terrestrial Users
5-NS-2	Laser Ranging
5-NS-3	Autonomous Navigation Systems for Space
5-NS-4	Surveillance Systems
5-NS-5	Collision Avoidance System Techniques
5-NS-6	Search and Rescue Systems
EARTH OBSERVATIONS	
EARTH PHYSICS	
6-EP-1	Photographic Coverage of the Earth
6-EP-2	Identification of Volcanic Activity

Cluster No.	Title
AGRICULTURE, FOREST, AND RANGE RESOURCES	
6-A/F-1	Crop Inventory and Land Use
6-A/F-2	Soil Type Mapping
6-A/F-3	Crop Identification
6-A/F-4	Crop Vigor and Yield Prediction
6-A/F-5	Wildfire Detection and Mapping
GEOGRAPHY, CARTOGRAPHY, AND CULTURAL RESOURCES	
6-G/C-1	Photographic and Multisensor Mapping
GEOLOGY	
6-G-1	Rock and Soil Type Identification
6-G-2	Use of Earth's Crust to Store and Condition Commodities or Waste
6-G-3	Geologic Disaster Avoidance
6-G-4	Utilization of Geothermal Energy Sources
6-G-5	Mineral and Oil Deposit Discovery
6-G-6	Identification of Land Forms and Structural Forms
HYDROLOGY AND WATER RESOURCES	
6-H-1	Determination of Pollution in Water Resources
6-H-2	Flood Warning and Damage Assessment
6-H-3	Synoptic Inventory of Major Lakes and Reservoirs
6-H-4	Synoptic Inventory of Snow and Ice
6-H-5	Survey of Soil Moisture in Selected Areas of the North American Continent
6-H-6	Location of Underground Water Sources in Selected Areas
6-H-7	Survey of Hydrologic Features of Major River Basins

Cluster No.	Title
OCEANOGRAPHY AND MARINE RESOURCES	
6-O-1	Ocean Pollution Identification, Measurement, and Effects
6-O-2	Solar Energy Partition and Heating in the Sea Surface Layer
6-O-3	Ocean Population Dynamics and Fishery Resources
6-O-4	Ocean Currents and Tide Forecasting
6-O-5	Ocean Physical Properties
6-O-6	Ocean Solid Boundary Processes
6-O-7	Ocean Surface Activity Forecasting
METEOROLOGY	
6-M-1	Determination of Boundary Layer Exchange Processes Using IR Radiometry
6-M-2	UHF Sferics Detection
6-M-3	Atmosphere Density Measurements by Stellar Occultation
6-M-4	Zero-G Environment Cloud Physics Experiment
6-M-5	Detection and Monitoring of Atmospheric Pollutants
6-M-6	Support of Studies of Special Geographical Areas

EARTH ORBITAL EXPERIMENT PROGRAM AND REQUIREMENTS STUDY

MANNED SPACEFLIGHT CAPABILITY

RESEARCH CLUSTER—1-BM-4
EFFECTS OF WEIGHTLESSNESS ON CIRCULATORY FUNCTION

C-1-1

RESEARCH CLUSTER SYNOPSIS--MANNED SPACEFLIGHT CAPABILITY

1-BM-4 Effects of Weightlessness on Circulatory Function

1. Research Objectives
The objective is to determine the effects of weightlessness on circulatory function, the detection and measurement of changes in circulatory function, the establishment of quantative time histories for the changes, and the investigation of basic physiological and biochemical processes involved in the changes.

An analysis of the potential areas of cardiovascular function warranting research in space resulted in the identification of 23 critical issues, categorized under the headings of Cardiac Activity, Blood Volume, Circulatory Dynamics, and Compensatory Reflexes. The described research program is responsive to these critical issues.

2. Background and Current Status
Cardiovascular observations in the form of the electrocardiogram (ECG) and arterial blood pressure have been included as an aspect of astronaut safety monitoring since the earliest Mercury flights. These paramaters are good indicators of acute changes but did not reflect the more chronic problems that were subsequently observed following the flight, manifested primarily in a pooling of blood in dependent veins and an associated orthostatic intolerance resulting in syncope when standing erect or during tilt-table tests. Subsequent tests during later Mercury flights and during the Gemini series also revealed a decrease in plasma volume and, in some cases, a reduction in red blood cell mass, as well as a degradation of some of the circulatory aspects of exercise tolerance.

Most of these changes were anticipated from the results of ground-based experiments in which the effects of weightlessness were simulated by prolonged bed rest which were started as early as 1945, or by water immersion reported in 1960 and 1961. Studies using these techniques are still continuing and are yielding valuable results.

The cardiovascular problems encountered in the early flights appear to have decreased in seriousness as the larger vehicles of the Apollo series permitted increased crew mobility and since specifically designed exercise programs have been introduced into the crew's activities. The evaluations, however, are based on limited preflight and postflight measurements. More-precise definitive data are expected to be derived from the experiments approved for inclusion in the Skylab A experiment program. These will include M-092, In-flight Lower-Body Negative Pressure; M-093, Vectorcardiogram; M-113, Blood Volume and Red Cell Life Span (Preflight and Postflight); and M-171, Metabolic Activity (including associated cardiovascular paramters), which deal, at least partially, with most of the previously noted problems.

3. Description of Research

At the conclusion of the Skylab A experiment program, it is anticipated that a number of questions will remain unanswered and problems unresolved. M-113 will involve preflight and postflight measurements only and should be repeated during a subsequent flight. The other experiments will have been performed on only a relatively small number of subjects over a limited exposure duration, and no comparison will have been made between conditioned and unconditioned subjects. A large amount of research therefore, remains to be accomplished in subsequent flights.

Skylab B, with the inclusion of modified capability IMBLMS, is expected to have greatly improved measurement capabilities over those of Skylab A. An experiment program is planned to concentrate on aspects of circulatory function expected to change most significantly during weightlessness: blood volume, circulatory compensation to venous pooling, and circulatory compensation to exercise. The time course of these changes will be carefully plotted during the first crew cycle by means of frequent measurements of the most directly variables, which include plasma volume, RBC volume, ECG, heart rate, and arterial blood pressure during rest, lower-body negative pressure (LBNP) stress, and stress of exercise on the bicycle ergometer. These experiments have been designated 1-101, 1-103, and 1-113 and are detailed in Phase II of A Requirements Study for a Biotechnology Laboratory for Manned Earth-Orbiting Missions, NASA CR 111794, 1970, and are summarized in Appendix H of this report.

Once the first set of experiments has been completed satisfactorily, some of the circulatory mechanisms associated with change in orthostatic and exercise tolerance will be examined during the second crew cycle. The measurement requirements will be increased by cardiac output and limb plethysmography, and the measurements previously associated with stress compensation will be repeated. Subtle changes in cardiac activity also will be carefully investigated by means of a group of sophisticated measurements, including vectorcardiography, phonocardiography, ballistocardiograpyy, and electromechanical delay. The circulatory experiments in the second crew cycle are designated 1-104, 1-106, and 1-116 of the earlier mentioned report.

During the third crew cycle, total body water and urine volume, specific gravity, Na, and pH will be measured in conjunction with plasma volume; and measurement of RBC survival time and fragility will be made in conjunction with RBC volume, to elucidate some mechanisms of the earlier measured changes. The relationship of changes in orthostatic tolerance with other aspects of circulatory dynamics will be examined by measurement of pulse wave velocity, and pulse wave contour during LBNP stress. These investigations are included in experiments 1-102 and 1-105.

No new measurements will be introduced during the fourth crew cycle, but many will be repeat to observe the effects of artificial-g, anticipated during the last 30 days of the cycle.

During the first and second crew cycles, many of the experiments will utilize both unconditioned subjects and exercise-conditioned subjects to determine the effectiveness of exercise as a counter-measure for undesirable changes in circulatory function: during the third crew cycle, LBNP-conditioned subjects will be used in a similar comparison.

It is anticipated that during the Skylab B experiment program all of the previously observed changes will be thoroughly quantified and many of the associated mechanisms defined. In addition, the areas of cardiac activity and circulatory dynamics will be measured sufficiently to uncover any previously unobserved changes in these functions. The experimental program recommended for conduct in the space station will be directed toward an investigation of additional mechanisms and associated or secondary effects of the original changes. The space station program is described in this experiment group.

It will be important at this point in the program to determine whether the observed deconditioning resides primarily in a reduced ability of the blood vessels to react with normal constrictions and dilations in response to blood volume shifts. This may be assessed by measuring venous compliance, arteriolar reactivity, and the response of the system as a whole to mechanically produced volume shifts. On the other hand, if the changes are produced by decrements in cardiac function they would potentially be evidenced in cardiac output changes accompanied potentially be evidenced in cardiac output changes accompanied by alterations in heart size. In conjunction with the above investigations, a study of the fragility of the capillaries, circulation time, and peripheral venous pressure would be of interest. The responsiveness of the reflex as such can be indicated by measuring the cardiovascular response to pressure reductions on the carotid sinus. The secondary effects of circulatory changes on intraocular blood pressures will also be evaluated.

Heart size may be estimated from x-ray photographs of the thorax taken both laterally and from the anterior-posterior direction. Capillary fragility is an easy test and is assessed from the results of a rubber tourniquet on the arm, termed the Rumpel-Leede test. An individually fitted cuff, capable of producing a negative pressure over the neck in the area of the carotid sinuses, will be required to measure reflex sensitivity, and a special pair of plethysmographic goggles will be required for measuring intraocular blood pressure. These procedures will be performed individually.

For the remainder of the measurements, the subject will be fitted with pneumatic cuffs on one arm and one leg, and plethysmographs for the measurement of limb volume will be applied distal to the cuffs. The volume of the limbs in association with various cuff pressures will permit an evaluation of arteriolar reactivity and venous compliance. On the free arm, arterial blood pressure will be measured with a modified sphygmomanometer and venous pressure by means of an indwelling needle connected to a pressure transducer. Changes in the pressures will be measured in association with occlusive-cuff inflation and Valsalva's maneuvers. Circulation time will be measured by the injection of decholin prior to the removal of the venous needle and timing the interval required for a taste sensation to occur. The first voiding following the test will be analyzed for stress hormones.

4. Impact on Spacecraft

The various measurements described for Skylab B related to circulatory function will produce a relatively small impact on the power, weight, and volume requirements. The major items of electronic equipment are an oscillographic display weighing about 50 lb occupying 3 cu ft and requiring about 60 w of power, and a strip chart recorder weighing 20 lb, occupying 1 cu ft and requiring 50 w. These two items, however, are not restricted to research on circulatory function but are utilized during experiments in almost every biomedical and behavioral area. Bioelectric sensing equipment, including such instruments as the electrocardiogram, vectorcardiogram, phonocardiogram, and impedance cardiogram, utilizes very light lead systems and a preamplifier, the entire assembly for each weighing approximately 2 lb and drawing about 1 w. Miscellaneous items, such as the blood pressure assembly, leg plethysmograph, and cardiotachometer are relatively small, weighing 3 to 5 lb requiring 10 w and occupying 30 cu ft.

Shielding for the isotopes required for blood volume measurements remains to be determined, but it should be minimal if spacecraft components are utilized.

All information will be recorded on magnetic tape, but this system must be considered basic to the spacecraft rather than a requirement produced by cardiovascular research.

Experiments recommended for the Space Station in the area of circulatory function will have the same basic equipment requirements and the Skylab B experiments. Additions will be restricted to light, small, low-powered miscellaneous items.

For both Skylab B and Space Station experiments, six subjects is a desirable number, with three unconditioned and three involved in some conditioning program for potential therapeutic use. Most operations can be performed by a trained medical or physiological technician, although a physician may be required for a limited number.

5. Required Supporting Technology Development
Before the research identified in this research cluster is begun, carefully controlled ground experiments are required for the development and refinement of techniques and procedures.

Most items of equipment require flight qualification; others, such as the impedance cardiograph used for cardiac output measurements and leg plethysmographs that accurately reflect small changes in blood flow require extensive development.

6. References

1. H. L. Taylor, L. Erickson, A. Henschel, and A. Keys. The Effect of Bed Rest on the Blood Volume of Normal Young Men. American Journal of Physiology, 144, 1945, pp. 227-232.

2. D. E. Graveline and B. Balke. The Physiological Effects of Hypodynamics Induced by Water Immersion, AF-SAM-60-88, U. S. Air Force School of Aviation Medicine, Brooks AFB, Texas, 1960.

3. E. L. Beckman, K. R. Coburn, and R. M. Chambers. Physiologic Changes Observed in Human Subjects During Zero-G Simulation by Immersion in Water Up to Neck Level. Aerospace Medicine, 32, 1961, pp. 1031-41.

4. D. E. Busby. Clinical Space Medicine: A Prospective Look at Medical Problems from Hazards of Space Operations, NASA-CR-856, 1967.

5. E. M. Roth. Compendium of Human Responses to the Aerospace Environment. Volume II. NASA-CR-1205 (II), 1968.

6. S. P. Vinograd. Medical Aspects of an Orbiting Research Laboratory. NASA SP-86, 1966.

Critical Issues Addressed by Research Cluster

1-BM-4

EFFECTS OF WEIGHTLESSNESS ON CIRCULATORY FUNCTION

1.1.1.1.1.1.1
What changes occur in the electrical activity of the heart and what are the mechanisms associated with the changes?

1.1.1.1.1.1.2
What changes occur in the force of contraction of the heart, and what are the mechanisms associated with the changes?

1.1.1.1.1.1.3
What changes occur in the heart sounds, and what is the origin of the changes?

1.1.1.1.1.1.4
What changes occur in heart size, and what are the reasons for the change?

1.1.1.1.1.1.5
What changes occur in heart rate, and what are the mechanisms associated with the changes?

1.1.1.1.1.2.1
What changes occur in plasma volume, and what are the mechanisms associated with the changes?

1.1.1.1.1.2.2
What changes occur in total body water, and what are the mechanisms associated with the changes?

1.1.1.1.1.2.3
What changes occur in extracellular fluid volume, and what are the mechanisms associated with the changes?

1.1.1.1.1.2.4
What changes occur in RBC mass, and why do the changes occur?

1.1.1.1.1.2.6
What changes occur in venous pressure, compliance, and stasis, and how are the changes brought about?

1.1.1.1.1.3.1
What changes occur in cardiac output, and what are the mechanisms associated with the changes?

1.1.1.1.1.3.2
What changes occur in circulation time, and what are the mechanisms associated with the changes?

1.1.1.1.1.3.3
What changes occur in pulse wave velocity, and what is the significance of the changes?

1.1.1.1.1.3.4
What changes occur in arteriolar reactivity, and what mechanisms are associated with the changes?

1.1.1.1.1.3.5
What changes occur in blood pressure, and what are the mechanisms associated with the changes?

1.1.1.1.1.4.3
What changes in normal circulatory compensatory activities are associated with the application of lower body negative pressure, and how are these changes manifested?

1.1.1.1.1.4.4
What changes in normal circulatory compensatory activities are associated with the use of occlusive pressure cuffs, and how are these changes manifested?

1.1.1.1.3.6.2.1
What changes occur in circulatory reflexes, and what are the mechanisms associated with the changes?

1.1.1.1.5.4.3
What effects do changes in excretory function have on plasma volume?

1.1.1.1.7.2.1
What changes occur in erythrocyte fragility, and what are the mechanisms associated with the changes?

1.1.1.1.7.2.2
What change occurs in the erythrocyte production rate, and what are the mechanisms associated with the changes?

1.1.1.1.7.2.3
What changes occur in the erythrocyte life span, and what are the mechanisms associated with the changes?

1.1.1.2.4.2
Can the variables normally measured in a routine physical examination still be used as indicators of the general health of the subject after prolonged exposure to zero-G?

EARTH ORBITAL EXPERIMENT PROGRAM
AND REQUIREMENTS STUDY

MANNED SPACEFLIGHT CAPABILITY

RESEARCH CLUSTER–1-BM-5
RADIATION, TOXICOLOGY, AND MEDICAL PROBLEMS

C-1-9

RESEARCH CLUSTER SYNOPSIS--
MANNED SPACEFLIGHT CAPABILITY

1-BM-5 Radiation, Toxicology, and Medical Problems

1. Research Objectives

The objective of the research cluster is the investigation of potential problems in clinical medicine and tolerance to radiation and toxicology produced by the altered state of the individual in weightlessness.

The research described in this research cluster is responsive to the following long-range objectives in biomedicine:

1. Determine the spacecraft gaseous atmosphere requirements for various space missions, including safety limits for toxic inhalants.

2. Determine the space radiation effects and hazards of space operations and define protective measures.

3. Define and develop predictive, diagnostic, and therapeutic procedures, medications, and equipment to maintain the health and well being of the crew.

The present research cluster considers primarily the detection of changes in the tolerance to radiation and toxic contaminants, and the response to standard treatments and medications.

An analysis of the potential areas of radiation and toxicological tolerance and medical problems warranting research in space resulted in the identification of 13 critical issues categorized under the headings of Respiratory Ciliary Activity, Traumatic Injuries, Radiation Tolerance, and Tolerance to Toxic Contaminants. The described research program answers many of the information requirements of these critical issues.

Maximum permissible exposures (MPE's) for radiation and threshold limit values (TLV's) for various toxic contaminants have been set for terrestrial situations. It must be determined whether these limits are valid for long-duration spaceflight in view of the potentially changed physiological state of the crew resulting from zero-g exposure. Similarly, the treatment and predicted healing characteristics for traumatic injuries on Earth may be altered in spaceflight. To ensure crew health and safety on long-duration missions, the validity of our present limits must be investigated and new limits set when warranted.

2. **Background and Current Status**

The techniques for establishing radiation and toxicological limits in terrestrial laboratories are recognized as standard procedures. Small mammals, cats, and mice are generally employed for this purpose as well as for the investigation of a large number of medical problems. No experiments in space are currently planned in this research area.

The requirements for small rodents in spaceflight have been thoroughly investigated in a number of laboratories, the most prominent being the work of Dr. P. Meehan at the University of Southern California in developing a space-qualifiable rodent research facility.

An experiment concerning the circadium rhythm in pocket mice, S-071, is scheduled for conduct on Skylab A. Although this experiment will contribute very little toward the objectives of the subject research cluster, it will provide valuable information concerning the maintenance of rodents in space.

3. **Description of Research**

The experiments in this research cluster were designated 1-222, 1-232, 1-233, and 1-234 in Phase II of A Requirements Study for a Biotechnology Laboratory for Manned Earth-Orbiting Missions, NASA CR111794. All were recommended for conduct aboard the Space Station rather than Skylab B.

Small laboratory animals will be used as the experimental subjects. Injuries and lesions of the type that could occur to astronauts in spacecraft accidents, such as lacerations, burns, and bone fractures, will be inflicted on the experimental animals. They will be sacrificed during flight at specified intervals, frozen, and returned for detailed examination. A second group will be orbited intact, and after approximately three weeks of flight, they will be exposed to predetermined radiation doses. Blood changes will be monitored for 30 days, after which all subjects will be sacrificed and returned to Earth. A third group will be treated similarily with predetermined concentrations of toxic contaminants.

Rats will be used for the study of clinical lesions. Six will be the subjects of lacerations, six of burns, and six of bone fractures produced shortly before launch. Standard treatments will be administered preflight and continued during the flight. Animals from each group will be sacrificed weekly during flight and frozen for return.

Five groups of six mice each will be flown for 3 weeks and then exposed to radiation doses of 25, 50, 100, 200 and 400 rem, respectively. Complete blood counts and differentials will be made daily for the first week, three times the second week, twice the third and fourth weeks after exposure. All fatalities will be preserved for return, and all survivors at the end of 4 weeks will be sacrificed and preserved for return.

Three groups of 20 mice each will be flown for 3 weeks and then exposed to toxic contaminants producing pulmonary irritation, CNS depression, and kidney damage, respectively. The concentrations will be those previously determined to be the LD-50 for the particular toxicant. Fatalities will be preserved for return, and survivors at the end of 30 days following exposure will be sacrificed and preserved for return.

4. Impact on Spacecraft

The major areas of impact that this research cluster will have on the space station are the requirements for animal housing and maintenance, radiation exposure, exposure to toxic contaminants, and crew participation.

Approximately 35 to 40 cu ft of space will be required for animal housing not including space for automatic food and water dispensing and automatic waste management. Housing should include a sufficient number of cages to segregate animals involved with specific procedures, but all may utilize the same controlled environment. The animals involved in this experiment group would be expected to consume approximately 100 lb of food, 65 lb of water, and 100 lb of oxygen. The animals could be launched with the vehicle; when frozen for return to Earth, they would weigh about 14 lb. A freezer capable of -70°F temperatures will be required to accommodate these specimens.

The radiation source would probably be an x-ray source from 70 to 250 kVp and from 30 to 200 ma. Such a tube or tubes would have to be developed and consequently would not presently have defined weight and power, a weight of 200 lb and power requirements of 500 to 1, 000 w during exposure are gross approximations.

The chamber for toxicological exposure would also have to be developed. It might be expected to weigh 25 to 50 lb, occupy 3 to 4 cu ft and require 5 to 10 w of power when in operation. It must be associated with a mass spectrometer or similar instrument for analyzing contaminant concentrations.

Crew participation would be rather extensive and would include animal care involving feeding and waste management (if these operations are not automated), frequent observation of animal health and viability, and treatment, as scheduled by the experiment protocol. Blood sampling of radiated animals would involve sample taking, sample dilution, cell counting, slide preparation and staining, and cell identification and counting. Animal sacrifice and preservation would complete the experimental tasks.

The experimental activities will require some experience and training, probably not beyond the technician level. One crewman could be trained to perform all of the required tasks, although it would be more practical to expect one crewman to be trained in blood counts, one in radiation administration, and one in toxicological exposure, with the other tasks divided.

5. Required Supporting Technology Development

Animal housing and automated maintenance must be studied and developed. A number of experiments are being suggested with similar requirements, and some studies are presently under way, particularly in space biology. The results of these investigations would have to be adapted to the peculiar requirements of this research cluster.

The experimental protocol requires an x-ray unit (or an alternative radiation source) capable of administering radiation doses (whole-body radiation) of from 25 to 400 rem to groups of animals. Its weight, power, volume, and operation should be consistent with spacecraft use. If possible, it should be combined with a diagnostic x-ray unit for efficiency. Units meeting some of these requirements currently exist, but they are not compatible with spacecraft use. Once developed, the unit must be integrated into the spacecraft to utilize spacecraft structure as part of its shielding; this will probably require extensive study.

Supporting research and technology will also be required for the development of a small chamber capable of maintaining specified levels of toxic contaminants for varying lengths of time for exposing groups of small mammals. Its weight, power, volume, and operation must be compatible with spacecraft use. Such chambers are available in terrestrial laboratories, but gross modification would be necessary for spaceflight use.

6. References

1. McDonnell Douglas Astronautics Report: Phase II of a Requirements Study for a Biotechnology Laboratory for Manned Earth-Orbiting Missions. NASA CR111794, 1970.

2. H. E. Johns. The Physics of Radiology. Charles C. Thomas, Springfield, Illinois, 1961.

3. J. D. MacEwen. Contaminant Generation Methods and Techniques. Proceedings of the Conference on Atmospheric Contamination in Confined Spaces. AMRL-TR-65-230, April 1965.

4. A. A. Thomas. Chamber Equipment Design Consideations for Altitude Exposures. Proceedings of the Conference on Atmopsheric Contamination in Confined Spaces, AMRL-TR-65-230, April 1965.

5. E. H. Vernot. Analytical Control of Contaminant Concentration in Exposure Chambers. Proceedings of the Conference on Atmospheric Contamination in Confined Spaces, AMRL-TR-65-230, April 1965.

6. D. E. Busby. Clinical Space Medicine, NASA CR-856, July 1967.

Critical Issues Addressed by Research Cluster

1-BM-5

RADIATION, TOXICOLOGY, AND MEDICAL PROBLEMS

1.1.1.1.2.4.1
What changes occur in the ejection of foreign particles from the respiratory tract by ciliary activity?

1.1.1.2.3.1
What changes occur in the healing rates for lacerations, contusions, and abrasions, and what mechanisms are associated with the changes?

1.1.1.2.3.2
What changes occur in the healing rates for burns, and what mechanisms are associated with the changes?

1.1.1.2.3.3
What change occur in the rates for fracture healing, and what mechanisms are associated with the changes?

1.1.1.2.3.7
Do the changes that occur in the healing process following non-infectious traumatic injuries necessitate any revisions in the treatment of the injury or the disposition of the injured crewman?

1.1.1.3.7.1
What changes occur in the LD50 of experimental animals exposed to a standard radiation source, and what mechanisms are associated with the changes?

1.1.1.3.7.2
What changes occur in the radiation dose required to produce symptoms of radiation sickness in experimental animals subjected to acute whole body exposure?

1.1.1.3.7.3
What changes occur in the radiation dose necessary to produce hematological effects in experimental animals, and how will the effects compare with those produced in ground-based experiments?

1.1.1.3.7.4
What changes occur in the radiation dose necessary to produce dermal effects in experimental animals, and how will the effects compare with those produced in ground-based experiments?

1.1.1.3.7.5
Do changes in tolerance to radiation in experimental animals during prolonged weightlessness result in any revision in radiation limits in the spacecraft environment?

1.1.1.3.8.1
What changes occur in the LD50 and LC50 of various compounds for experimental animals during prolonged weightlessness, and what is the mechanism responsible for the change?

1.1.1.3.8.2
What changes occur in the normally anticipated symptoms in experimental animals exposed to various levels of toxic contaminants, and what are the mechanisms responsible for the changes?

1.1.1.3.8.3
Do changes in tolerance to toxic contaminants in experimental animals exposed to prolonged weightlessness result in any revision of threshold limit values (TLV's) established from ground-based experiments?

EARTH ORBITAL EXPERIMENT PROGRAM AND REQUIREMENTS STUDY

MANNED SPACEFLIGHT CAPABILITY

RESEARCH CLUSTER—1-BM-6
EFFECTS OF WEIGHTLESSNESS ON STRESS RESPONSE

C-1-16

RESEARCH CLUSTER SYNOPSIS—MANNED SPACEFLIGHT CAPABILITY

1-BM-6 Effects of Weightlessness on Stress Response

1. Research Objectives

The objective of the present research cluster is to determine, during weightless space flight, changes in physiological responses and tolerance limits to potential environmental stresses in order to better define physiological design criteria for spacecraft.

There is no single long-range objective in biomedicine to which the research described in this research cluster is responsive, although the objective, "Assure that human tolerance limits for acceleration, vibration and noise are defined for specific missions," would be most applicable. It appears by implication, that this objective includes all environmental stresses to which the astronaut might be exposed. Satisfying this objective requires first, that human tolerance limits be re-established, insofar as they may have been altered as a result of zero-g deconditioning; the spacecraft's nominal and emergency limits must then be set in accordance with the limits of human tolerance.

An analysis of the areas of stress liable to be affected by physiological changes induced by weightlessness resulted in the identification of 40 critical issues categorized under the headings of Tolerance to Reduced Oxygen, Tolerance to Increased Carbon Dioxide, Tolerance to Temperature Variations, and Exercise Tolerance. The described research program supplies information requirements for these critical issues.

The experiments in this research cluster are recommended for Space Station conduct after the various potential physiological changes have been well established. It will be desirable to test changes in stress response during the period of maximum physiological change, since they are expected to be responsible for changes in stress response.

2. Background and Current Status

The definition of spacecraft limits for oxygen and carbon dioxide concentrations, temperature extremes, and workload assignments are based on human tolerance limits established over many years of ground-based experimentation. The physiological compensatory reflexes that are activated by a stressful change in an environmental parameter are responsible for the normal level of human tolerances, and are merely specific manifestations of standard physiological activities. Many of these activities are involved in reactions that have been observed to deteriorate in the space environment. It follows that stress responses may also undergo deterioration and that the defined spacecraft limits may no longer be valid.

There are numerous reports of reductions in exercise tolerance both in postflight tests on astronauts and during ground-based bed-rest and water-immersion studies. A reliable quantitation of this reduction will necessitate in-flight measurements, the first of which is scheduled for Skylab A, Experiment M-171, Metabolic Activity. Additional tests are recommended throughout the experiment program.

No reports have been received on reduced tolerance to other stresses; it is possible, however, that no situations have occurred in space for opportunistic measurements. No tests of this sort were scheduled.

It is not unreasonable to anticipate some alterations. The increase in heart rate and peripheral vasoconstriction that occur in response to acute hypoxia are also required to maintain orthostatic tolerance (known to be reduced from zero-g exposure). The alterations in fluid and electrolyte balance anticipated in space crewmen may well reduce the body's buffering capacity for increases in H_2CO_3 with increased environmental CO_2. The commonly reported losses of plasma volume would certainly be expected to affect the consequences of peripheral vasodilatation in response to heat and, conversely, would possibly increase tolerance to cold.

Skylab A will not include any stress-response experiments other than the one mentioned previously on metabolic activity. Many of the experiments, however, will produce information of value on the status of the physiological mechanisms potentially involved in the stress responses. These include: M-071 and M-073, Mineral Balance and Bio-Assay of Body Fluids; M-092, In-flight Lower-Body Negative Pressure; M-113, Blood Volume and Red Cell Life Span.

3. Description of Research

A more detailed examination of changes in exercise tolerance is recommended for the Skylab B program. The research activities will include a careful quantitation of the time history of the change and an evaluation of the role of oxygen consumption, carbon dioxide production, cardiac output, and maximal oxygen consumption in the changes. These experiments are designated 1-115 and 1-116 and are detailed in Phase II of A Requirements Study for a Biotechnology Laboratory for Manned Earth-Orbiting Missions, NASA CR111794, and summarized in Appendix H of this report. In addition, three Advanced Skylab experiments, 1-124, 1-125, and 1-128 utilize exercise and LBNP stresses for therapeutic conditioning.

Most of the tests included in this research cluster are scheduled for implementation during the Space Station experiment program. Experiment 1-210, Changes in Oxygen Debt with Calibrated Exercise, is similar to experiment 1-116, but it includes the measurement of blood lactic acid concentration for the estimation of oxygen debt. The measurement of blood lactic acid was not included in the earlier program because it was not listed among the capabilities of IMBLMS. The analysis must be performed immediately after the blood is drawn and cannot, therefore, be made on returned samples.

Responses to hypoxia will be measured by having the subject breath from a gas mixture containing oxygen at a subnormal pressure. The oxygen concentration will be decided upon before flight but should be similar to the oxygen pressure at 30,000 ft (approximately 450 mm Hg). Time of useful consciousness will be estimated by the duration of exposure prior to deterioration of a moderately complex manual task. Oxygen and carbon dioxide in the expired air will be measured by the metabolic analyzer on a breath-by-breath basis.

The respiratory response to CO_2 will be measured by successively exposing the subjects to gas mixtures containing 3-, 5-, and 7-percent, CO_2 respectively (percent of 760 mm Hg). During 10 minutes of breathing each mixture, the respiratory minute volume will be measured by the metabolic analyzer, and alveolar CO_2 will be determined by the analysis of end-tidal (alveolar) air collected by a Rahn end-tidal sampler and measured in a CO_2 analyzer. Respiratory minute volume will be plotted subsequently against alveolar CO_2 to define the respiratory response.

In order to determine the response of each subject to hyperthermia, a thermal enclosure will be required; this may be a large chamber capable of accommodating a subject and a bicycle ergometer, or possibly an individually fitted thermal garment similar to a full pressure suit capable of controlling internal temperature by variations in ventilating air flow rate and temperature. During two separate exposures, the response of the resting and exercising subject is measured. Tolerance is defined as the length of exposure required to produce a specified core temperature or heart rate, whichever occurs first. Resting limits are usually specified as 102° F and 150 beats per minute.

Six subjects should participate in the program. The duration and frequency of the tests will be governed by the deconditioning trend curves established on previous flights. Measurements made twice weekly during the first 3 weeks of the crew cycle is a potential schedule.

The experiments described in this research cluster were designated 1-210, 1-215, 1-216, and 1-231 in the earlier-mentioned biotechnology laboratory study

4. Impact on Spacecraft

The metabolic analyzer and bicycle ergometer are common to a large number of experiments. The metabolic analyzer weighs about 40 lb, occupies 3 cu ft, and requires 30 w for its operation. The bicycle ergometer weighs 50 lb, occupies 4 cu ft stowed, but requires 20 cu ft and 10 w of power for its operation.

About 150 to 175 lb of gas mixtures will be required for the hypoxia and hypercapnia response experiments. The containers for the gases and the pressure under which they are stored must be determined during the spacecraft design. The associated metabolic analyzer has been mentioned. All other associated equipment has minimal impact.

The thermal enclosure could have a very significant impact. This item requires extensive development, however, and the impact of its final design cannot be predicted at this time.

Crew time and skill requirements for conducting experiments in this research cluster are not extensive. All experiments must be carefully monitored by a thoroughly trained observer, and since the experiments are in the category of provocative testing, a physician should be available in case of unforseen emergencies.

5. Required Supporting Technology Development
Most items of equipment associated with this research cluster already exist, or are currently under development for the Skylab I program, or can be derived from existing equipment after minor modifications. The one major exception to this is the thermal enclosure required for determining the response to hyperthermia; this item will require extensive research and development. The chamber should be capable of producing and maintaining internal temperatures up to 176°F during the period of operation (up to 2 hours). It should be capable of maintaining its preset temperature within ±2°F, even during a period of subject exercise and consequent heat generation. It should be capable of restricting relative humidity to about 10 percent, and its wall temperature should not be appreciably different from its air temperature. Although an enclosure with an anthropomorphic shape would appear to be most convenient, it may not be practical from a development standpoint.

6. **References**

1. Requirements Study for a Biotechnology Laboratory for Manned Earth Orbiting Missions. NASA CR111794, 1970.

2. C.F. Consolozio, R.E. Johnson, and L.J. Pecora. Physiological Measurements of Metabolic Functions in Man. McGraw Hill Book Company, New York, 1963.

3. D.E. Busby. Clinical Space Medicine, NASA CR-856. July 1967.

4. S.M. Tenney and T.W. Lamb, Physiological Consequences of Hypoventilation and Hyperventilation. Handbook of Physiology: Respiration Volume II. American Physiological Society, Washington, D.C., 1965.

5. U.C. Luft. Aviation Physiology--The effects of altitude. Handbook of Physiology: Respiration Volume II. American Physiological Society, Washington, D.C., 1965.

6. D.H.K. Lee. Terrestrial Animals in Dry Heat: Man in the Desert. Handbook of Physiology: Adaptation to the Environment. American Physiological Society. Washington, D.C., 1964.

7. J.A. Gillies. A Textbook of Aviation Physiology. Pergamon Press, London, 1965.

Critical Issues Addressed by Research Cluster

1-BM-6

EFFECTS OF WEIGHTLESSNESS ON STRESS RESPONSE

1.1.1.1.1.3.1
What changes occur in cardiac output, and what are the mechanisms associated with these changes?

1.1.1.1.1.3.5
What changes occur in blood pressure, and what are the mechanisms associated with these changes?

1.1.1.1.1.4.1
What changes in normal circulatory compensatory activities are associated with exercise, and how are these changes manifested?

1.1.1.1.1.4.3
What changes in normal circulatory compensatory activites are associated with the production of lower body negative pressure, and how are these changes manifested?

1.1.1.1.1.4.5
What changes in normal circulatory compensatory activities are associated with environmental stresses?

1.1.1.1.2.3.2
What changes in normal pulmonary ventilation adjustments are associated with exposure to increased environmental CO_2 levels?

1.1.1.1.2.3.3
What changes in normal pulmonary ventilation adjustments are associated with exercise?

1.1.1.1.2.3.4
What changes in normal pulmonary ventilation adjustments are associated with exposure to reduced environmental oxygen levels?

1.1.1.1.2.3.5
What changes in respiratory compensatory activities are associated with other environmental stresses?

1.1.1.1.3.6.2.1

What changes occur in circulatory reflexes, and what are the mechanisms associated with the changes?

1.1.1.1.3.6.2.3
What changes occur in respiratory reflexes, and what are the mechanisms associated with the changes?

1.1.1.1.6.2.2
What changes occur in the accumulation of oxygen debt associated with defined metabolic loads, and what are the mechanisms associated with the changes?

1.1.1.2.5.2.1
What form of exercise is best suited to the prevention of the occurrence of deleterious biomedical changes?

1.1.1.2.5.2.2
How much time per day must be spent on the exercise program to prevent the occurrence of deleterious biomedical changes?

1.1.1.2.5.7
Can conditioning programs reverse physiological changes?

1.1.1.3.1.1.1
What changes occur in the effects of hypoxia on the time of useful consciousness (TUC), and what are the mechanisms associated with the changes?

1.1.1.3.1.1.2
What changes occur in the effects of hypoxia on vision, and what are the mechanisms associated with the changes?

1.1.1.3.1.1.3
What changes occur in the effects of hypoxia on the electroencephalogram, and what are the mechanisms associated with the changes?

1.1.1.3.1.2.1
What changes occur in cardiac response to hypoxia and what mechanisms are associated with the changes?

1.1.1.3.1.2.2
What changes occur in the vascular response to hypoxia, and what mechanisms are associated with the changes?

1.1.1.3.1.2.3
What changes occur in the effects of hypoxia on the electrocardiogram, and what are the mechanisms associated with these changes?

1.1.1.3.1.3.1
What changes occur in the ventilatory response to hypoxia, and what are the mechanisms associated with these changes?

1.1.1.3.1.3.2
What changes occur in the effects of hypoxia on blood oxygenation, and what are the mechanisms associated with these changes?

1.1.1.3.1.5.2
Do changes in response and tolerance to hypoxia during prolonged weightlessness result in any modification in the normal and emergency limits for oxygen concentrations in the spacecraft atmosphere?

1.1.1.3.2.1
What changes occur in the ventilatory response to elevated atmospheric CO_2, and how do the changes affect the alveolar CO_2 levels?

1.1.1.3.2.2
What changes occur in the cardiovascular response to elevated atmospheric CO_2, and how does the response affect the alveolar CO_2 levels?

1.1.1.3.2.3
What variations occur in blood pH and bicarbonate levels, and are the changes related to changes in the blood buffering mechanisms?

1.1.1.3.2.4
Do changes in response and tolerance to carbon dioxide during prolonged weightlessness result in a revision of the normal and emergency limits imposed on carbon dioxide concentrations in the spacecraft atmosphere?

1.1.1.3.5.1.1
What changes occur in the time required to reach physiological limits in core temperature and average body temperature with exposure to elevated environmental temperatures, and which of the measured sites shows the greatest change?

1.1.1.3.5.1.2
What changes occur in the cardiovascular response to elevated environmental temperatures, and what are the mechanisms associated with these changes?

1.1.1.3.5.1.3
What changes occur in respiratory rate, ventilation rate, and the composition of alveolar air associated with exposure to elevated environmental temperatures, and what are the mechanisms associated with these changes?

1.1.1.3.5.1.4
What changes occur in the normal sweating response to elevated environmental temperatures, and what significance are the changes in temperature regulation?

1.1.1.3.6.1
What changes occur in the oxygen consumption and metabolic rates associated with various work loads, and what are the mechanisms associated with these changes?

1.1.1.3.6.2
What changes occur in the cardiovascular response to strenuous work, and what are the mechanisms associated with these changes?

1.1.1.3.6.3
What changes occur in the ventilatory response to strenuous work, and what changes occur in the composition of alveolar gases?

1.1.1.3.6.4
What changes occur in maximal oxygen consumption, and what are the mechanisms associated with these changes?

1.1.1.3.6.5
What changes occur in the oxygen debt associated with various work loads, and what is the significance of the change in exercise tolerance?

1.1.1.3.6.6
What changes occur in body temperature regulation during exercise, and what are the mechanisms associated with these changes?

1.1.1.3.6.7
Do changes in response and tolerance to strenuous exercise during prolonged weightlessness result in any modifications to work load limitations imposed on the spacecraft crew?

EARTH ORBITAL EXPERIMENT PROGRAM
AND REQUIREMENTS STUDY

MANNED SPACEFLIGHT CAPABILITY

RESEARCH CLUSTER–1-BM-7
EFFECTS OF WEIGHTLESSNESS ON THE NERVOUS SYSTEM

C-1-25

RESEARCH CLUSTER SYNOPSIS--MANNED SPACEFLIGHT CAPABILITY

1-BM-7 Effects of Weightlessness on the Nervous System

1. RESEARCH OBJECTIVES. The objective of the research cluster is the determination of the existence, time-course, and mechanisms of changes that may occur in the nervous system because of a long duration exposure to weightlessness.

The research described in this research cluster is responsive to NASA's specific, long-range objective in biomedicine which is to "Investigate and evaluate the effects of spaceflight on neurophysiological function including equilibrium, coordination, sleep, alertness, biorhythms, visual and other special senses." Dividing the study discipline of Manned Spaceflight Capability into its various areas and subdisciplines, the areas of neurophysiological function that are generally associated with psychology were assigned to Behaviroal Research, including vision, audition and all special and somatic senses, psychomotor capabilities and skill retention; and also aspects of orientation, sleep alertness, and circadian rhythms. Biomedicine is concerned with the more direct measurements of neurophysiological function, including reflex testing and electrophysiological measurement. An analysis of the areas of neurophysiology potentially applicable to biomedical research in space resulted in the identification of 20 critical issues categorized under the headings of Vestibular Function, Electroencephalographic Changes, and Skeletal Muscle Reflexes. The critical issues applicable to autonomic reflexes are examined under the appropriate related systems (such as cardiovascular reflexes and respiratory reflexes). The information requirements for the other critical issues are supplied by the described research program.

Except for a few cases of motion sickness and reported disorientation, few alterations have been observed in neurophysiological function. Consequently, most observations will be directed toward detecting changes rather than quantitizing previously established alterations, and will be generally limited to the earlier phases of the crew cycle.

2. BACKGROUND AND CURRENT STATUS. Some of the earliest reports of problems during spaceflight were those of nausea and disorientation during the initial Russian flights. Such problems did not appear to a significant extent in U.S. flights until the Apollo flights, where the crewmen had greater freedom and mobility. The problems of the U.S. astronauts were primarily restricted to nausea. It has been hypothesized that the reduction in sensory inputs during weightlessness and confinement may, in turn, decrease stimulation of the reticular activating system, and therefore reduce electroencephalographic (EEG) and alpha blocking and alertness. Thus far in the space program, these changes have not been manifest. Changes in neurophysiological function during ground-based simulations would not be readily extrapolated to the space situation.

The initial significant data from spaceflights are expected to be derived from two Skylab A experiments; M-131, Human Vestibular Function, and M-133, Sleep Monitoring. The experiment on vestibular function is a carefully designed experiment using a specially constructed rotating litter chair to detect changes in otolith and semicircular canal function, orientation, and susceptability to motion sickness. M-133 will investigate sleep patterns by an automatic analysis of electroencephalographic (EEG) and electrooculographic (EOG) records taken during selected sleep periods of one astronaut. These experiments are expected to supply information concerning neurophysiological functions in space and to enable subsequent experiments to investigate advanced aspects of these problems.

3. DESCRIPTION OF RESEARCH. Most aspects of vestibular function accessible to investigation will be covered by Skylab A, experiment M-131; it is anticipated, however, that some verification of the results will be desired and that the data will suggest additional experiments. To accommodate further experimentation of this type, a relatively open-ended vestibular experiment is recommended for the Skylab B Program. EEG studies, in separate experiments, will include both sleep and waking measurements. Sleep survey questionnaires and performance of subjects aroused from selected sleep stages will be correlated with changes in EEG and EOG sleep stage patterns; and the frequency and duration of EEG desynchronization will be compared to the subject's waking performance. These experiments are designated 1-109, 2-117, 1-110 and 1-111 and are detailed in Phase II of <u>A Requirements Study for a Biotechnology Laboratory for Manned Earth Orbiting Mission</u>, NASA CR111794, and are summarized in Appendix H of this report.

More-detailed information on the effects of weightlessness on CNS function and the brain areas and mechanisms involved will have to be derived from animal studies. Two such experiments, one investigating the changes in the electrical activity of higher centers in the cat and one investigating changes in the cat's vestibular apparatus and related structures, have been recommended for conduct in the Mid Space Station. These experiments were designated 1-223 and 1-224 in the above-mentioned biotechnology laboratory study and are included in Experiment Research Cluster 1-BM-12 of the present report.

Although the spinal reflexes of the peripheral nervous system are theoretically less susceptible to the effects of the zero-g than is the central nervous system, some degradation could occur, either through a loss of tone in the effector muscles or through changes in hormonal influences. It is desirable, therefore, to carefully examine various aspects of the reflex functions for evidence of change. This study is detailed in the subject research cluster.

The measurements involved are similar to those made during a clinical neurological examination except that more-quantitative methods of evaluation have been substituted wherever possible. Changes in the activity of nine of the cranial nerves (oculomotor, trochlear, trigeminal, abducens, facial, glossopharnygeal, vagus, accessory, and hypoglossal) will be superfically evaluated by standard clinical tests; olfaction, vision, audition, and spatial orientation will be examined in detail in experiments described in the Individual Behavior area. Superficial spinal reflexes, as exemplified by the abdominal reflexes, will be subjectively evaluated by the experimenter and more quantitatively measured by electromyographic recordings of the responding abdominal musculature's strength of contraction. Deep tendon reflexes will be represented by the biceps and triceps reflexes of the arm, and the knee and ankle jerk reflexes of the leg. These reflexes will be elicited by tendon taps and their activity evaluated by observation, electromyography, and the application of accelerometers.

Six subjects should be examined weekly for the first 4 weeks of the crew cycle and once every 2 weeks thereafter for the duration of the cycle.

4. IMPACT ON SPACECRAFT. The various measurements described for Skylab B will have the greatest impact on the spacecraft. The EEG leads and associated electronics will not be a major contributor, weighing only 1 lb, occupying 0.05 cu ft, and requiring only 1 w of power. The supporting oscillographic display will weigh 50 lb, occupy 3 cu ft, and require 60 w, but it is not unique to these experiments. On the other hand, the rotating litter chair associated with the vestibular experiments weighs 210 lb, occupies 20 cu ft stowed and 30 cu ft during operation, and requires 200 w when rotating with momentary 400-w peaks. The associated measuring equipment, electromyograph, and electro-oculograph together weigh only 3 lb, occupy 0.15 cu ft and require 2 w.

   Compared with the above rather-massive equipment, the items associated with reflex testing are quite negligible, consisting primarily of small hand-held instruments. The electromyogram is described above, and the accelerometers should weigh only 1 or 2 ounces.

   The impact on crew activity is not great. Three to six subjects will be required for most experiments. Testing time is minimal for all experiments except 1-111, which will require approximately 1 hr per subject for each test period. Skill requirements are minimal except for reflex testing, which will require a highly experienced experimenter, probably a physician.

5. REQUIRED SUPPORTING TECHNOLOGY DEVELOPMENT. All techniques and equipment associated with vestibular and EEG experiments described for Skylab B are being developed for the Skylab A program and should, consequently, be qualified for subsequent use. The use of electromyography and accelerometers for the quantification of reflex response is not a technique currently in use and would have to be developed for spacecraft use. Accelerometers of a size that could be applied to a limb and not reduce its excursion would also require research and development.

6. REFERENCES

   1. Phase II of a Requirements Study for a Biotechnology Laboratory for Manned Earth Orbiting Missions, NASA CR111794, 1970.

   2. S.P. Vinograd. Medical Aspects of an Orbiting Research Laboratory, NASA SP-86, 1966.

3. A. Graybiel. Human Vestibular Function, M-131, NASA Experiment Implementation Plan, April 1967.

4. J.D. Frost. Sleep Monitoring Experiment, M-133, NASA Experiment Implementation Plan, March 1970.

5. B.H. Smith. Principles of Clinical Neurology, Year Book Medical Publishers, Inc., Chicago, Ill., 1965.

6. H.G. Armstrong. Neuropsychic Examination. Aerospace Medicine. Williams and Wilkins Company, Baltimore, 1961.

Critical Issues Addressed by Research Cluster

1-BM-7

EFFECTS OF WEIGHTLESSNESS ON THE NERVOUS SYSTEM

1.1.1.1.3.1.1.1
What changes occur in the susceptibility to motion sickness, and what are the mechanisms associated with the changes?

1.1.1.1.3.1.1.2
What changes occur in spatial orientation, and what illusions are associated with the changes?

1.1.1.1.3.1.1.3
What changes occur in sensitivity to linear acceleration, and what are the mechanisms associated with the changes?

1.1.1.1.3.1.1.4
What changes occur in the incidence of oculogravic and oculoagravic illusions associated with exposure to linear accelerations?

1.1.1.1.3.1.1.5
What changes occur in ocular counterrolling, and how are these related to changes in spatial orientation in weightlessness?

1.1.1.1.3.1.2.1
What changes occur in the susceptibility to motion sickness associated with rotation in zero-G, and what are the mechanisms associated with the changes?

1.1.1.1.3.1.2.2
What changes occur in sensitivity to angular acceleration, and what are the mechanisms associated with the changes?

1.1.1.1.3.1.2.3
What changes occur in the incidence and intensity of the oculogyral illusion and nystagmus during rotation in weightlessness, and what are the mechanisms associated with the changes?

1.1.1.1.3.1.2.5
What changes will occur in spatial orientation during rotation in zero-G, and what are the mechanisms associated with the changes?

1.1.1.1.3.3.1
What changes occur in the normal (alpha) rhythms associated with the resting awake state, and how are these differences manifested?

1.1.1.1.3.3.2
What changes occur in the mechanisms of "alpha blocking" associated with electroencephalographically observed arousal, and how are the changes related to objective manifestations of attention?

1.1.1.1.3.3.3
What changes occur in the EEG patterns associated with sleep, and how are the changes related to subjective feelings and objective evidence of sleep quality?

1.1.1.1.3.3.4
Do any EEG rhythms not included in the subject's normal patterns occur, and can these be related to personality or performance changes?

1.1.1.1.3.6.1.1
What changes occur in the extensor reflexes, and can the changes be related to changes in general myotatic activity?

1.1.1.1.3.6.1.2
What changes occur in the withdrawal reflexes, and can the changes be related to changes in neural or synaptic transmission?

1.1.1.1.3.6.1.3
What changes occur in reflex responsiveness or reflex spreading, and what mechanisms are associated with the changes?

1.1.1.1.3.6.1.4
What changes occur in reflex inhibition, and what are the mechanisms associated with the changes?

1.1.1.1.3.6.1.5
What changes occur in complex reflex patterns, and what are the mechanisms associated with the changes?

1.1.1.1.3.6.2.2
What changes occur in visual reflexes, and what are the mechanisms associated with the changes?

1.1.1.2.4.2
Can the variables normally measured in a routine physical examination still be used as indicators of the general health of the subject after prolonged exposure to zero-G?

EARTH ORBITAL EXPERIMENT PROGRAM
AND REQUIREMENTS STUDY

MANNED SPACEFLIGHT CAPABILITY

RESEARCH CLUSTER-1-BM-8

EFFECTS OF WEIGHTLESSNESS ON GASTRO-INTESTINAL FUNCTION

C-1-32

RESEARCH CLUSTER SYNOPSIS-- MANNED SPACEFLIGHT CAPABILITY

1-BM-8 Effects of Weightlessness on Gastrointestinal Function

1. Research Objective

The objective of the research cluster is the determination of changes in digestion, absorption, and gastrointestinal movements produced by prolonged exposure to weightlessness. The studies of changes in metabolism, nutritional requirements, and dietary habits are included in the objectives of other research clusters.

The research described in this research cluster is related to the long-range objective in biomedicine which is to "define nutritional requirements for space missions; improve food acceptability; and assess the effects of spaceflight on the gastrointestinal tract, including nutrition, ingestion, digestion, absorption, management of ingested gases, and elimination. Also included in the objective is the assurance of potable spacecraft water in terms of both chemical and biological acceptability."

The scope of the objective exceeds the range of this research cluster. Such areas as food acceptability, gas management, and elimination (from the subjects viewpoint) require subjective responses and will be investigated by means of questionnaires. Water management, waste management, and food management and processes are the topics of experiment group descriptions under Life Support and Protective Systems. The subject research cluster is responsive to aspects of the NASA objective concerned with ingestion, digestion, and absorption.

The research cluster will contribute to the information requirements of 37 critical issues categorized under the headings of Gastrointestinal Motility, Digestive Processes, and Absorption, which were derived from an analysis of the objective.

2. Background and Current Status

Both the astronauts and the mission planners have shown great interest in the nutritional and palatability aspects of the diet, indicating the importance of at least certain areas of digestive physiology. The more functional aspects, however, have not been the subject of experimental investigations other than the simple recording of crew comments concerning such physical problems as hunger, nausea, and gastrointestinal pain. No experiments are planned for the Skylab A Program and none was recommended for the Skylab B in Phase II of A Requirements Study for a Biotechnology Laboratory for Manned Earth-Orbiting Missions, NASA CR111794, 1970

No evidence of changes in gastrointestinal function has been noted in any of the prior spaceflights. Some weight loss and periods of nausea have been reported, but these are thought to be vestibular or metabolic in origin.

Experiments in this research cluster are designed primarily to reveal changes in gastrointestinal function if they exist.

3. Description of Research
Most of the initial information on gastrointestinal function will be derived from the administration of test meals and test substances, which will be followed by fecal analysis for unabsorbed components, supplemented in some cases by blood and urine analysis to determine resultant changes in blood levels.

Each test meal will be designed specifically for each of the individuals acting as subjects. The caloric content, and the amount of protein, carbohydrate, and fats will be based on the subject's body weight and the anticipated energy requirements of the mission. Each test meal will also contain dye markers to enable the collected feces to be related to the particular test meal.

During an extended control period before the flight, each of the actual subjects will be placed on a test-meal program, and his feces will be analyzed to determine the normal range and variations in his digestion and absorption of the various designated components. Deviations from the values established during flight should permit an evaluation of changes in the related gastrointestinal functions. Subsequent tests, specific for the implicated functions, would verify and detail the initial findings.

It is recommended that the feces be returned for analysis in a ground-based laboratory. To accomplish this, the feces are weighed wet on the specimen mass measurement device, completely dried, reweighed, sealed and stored onboard at room temperature until returned. The dispensing of packaged wet feces suitable for weighing and the drying of the feces will be a function of the ship's waste-management system.

During the period of test meal administration, the protein, lipid, and glucose concentrations of the blood and urine will be measured twice weekly. The measurements will be made on venous blood samples and 24-hour urine samples. In addition, once per week (not on a urine collection day), each subject will drink 25 gms of xylose in 250 ml of H_2O, followed by an additional 250 ml of H_2O. The subject voids immediately prior to xylose administration, and urine is collected for the subsequent 5 hours. An aliquot of 50 ml is extracted and analyzed spectrophotometrically for xylose. Xylose is a test for intestinal absorption of carbohydrate.

Measurements of gastrointestinal motility and pH will be made with the use of an ingested radiosonde. A receiver will pick up the signals from the radiosonde and record its position against time as it moves along the gastrointestinal tract. This technique is experimental at present and will require extensive research and development to increase the accuracy and reliability of its information, to reduce the experience and skill required on the part of the monitor, and to adapt it to spaceflight use.

4. Impact on Spacecraft

The major impact of experiments in gastrointestinal function on spacecraft systems will be in the requirements for an onboard analytical clinical chemistry laboratory; these requirements, however, are the subject of research cluster 1-BM-10 and are detailed in that description. The next major impact will be on the food and waste management systems. The special test meals must be prepared and packaged before flight and designated for the intended crewman. The composition of the meal in calories and foodstuff distribution should be based on the specific astronaut's size, predicted workload during the test period, and dietary habits. The waste-management system will be revised to accommodate the drying of feces and its weighing both wet and dry. The spacecraft must subsequently provide for the sealing, storage, and return of the dried feces. It is anticipated that storage will be at room temperature.

The endoradiosonde and its associated electronics are the only items of instrumentation unique to this experiment group, the specimen mass-measurement device being required by a number of research clusters. These items are small and light and require minimal power for operation.

Other than the endoradiosonde measurements and the blood and urine analysis, all operations in this experiment group are performed by the subjects themselves, minimizing the time requirements for trained technicians.

5. Required Support Technology Development

The operations required for the experiments in this research cluster are standard laboratory procedures and may be transposed to spacecraft use with little modification. Endoradiosonde measurements are the exception. Techniques for its use have not been standardized even in terrestrial laboratories and will require extensive development and simplification for use during spaceflight.

6. References

1. Requirements Study for a Biotechnology Laboratory for Manned Earth-Orbiting Missions. NASA CR111794.

2. S. P. Vinograd. Medical Aspects of an Orbiting Research Laboratory. NASA SP-86, 1966.

3. H. W. Davenport. Physiology of the Digestive Tract. Year Book Medical Publishers, Inc., Chicago, 1967.

4. R. W. Alnutt, W. C. Becker, and R. E. Barbiere. Techniques of Physiological Monitoring, Volume III--Systems. AMRL-TDR-62-98 (III), October 1964.

Critical Issues Addressed by Research Cluster

1-BM-8

EFFECTS OF WEIGHTLESSNESS ON GASTROINTESTINAL FUNCTION

1.1.1.1.3.6.2.4
What changes occur in gastrointestinal reflexes, and what are the mechanisms associated with the changes?

1.1.1.1.4.1.2
What changes occur in gastric motility, and to what extent will these changes influence gastric digestion of the foodstuffs?

1.1.1.1.4.1.3
What change occur in gastric emptying time, and to what processes are these changes related?

1.1.1.1.4.1.4
What changes occur in motility of the small intestine, and to what extent will these changes influence digestion of foodstuffs in the small intestine?

1.1.1.1.4.1.5
What changes occur in movements of the colon, and what effect will the changes have on fecal formation and defecation?

1.1.1.1.4.1.6
Will changes in gastric motility affect the incidence of nausea and the mechanics of vomiting?

1.1.1.1.4.2.1
What changes occur in salivary secretion, and what effects will the changes have on salivary digestion?

1.1.1.1.4.2.2
What changes occur in gastric secretion, and what effects will the changes have on gastric digestion?

1.1.1.1.4.2.3
What changes occur in pancreatic secretion, and what effects will the changes have on digestion within the small intestine?

1.1.1.1.4.2.4
What changes occur in the secretion of bile, and what effects will the changes have on fat digestion?

1.1.1.1.4.2.5
What changes occur in intestinal secretion, and what effects will the changes have on digestion in the small intestine?

1.1.1.1.4.2.6
Will changes in gastric secretion produce an increased incidence of hyperacidity and other gastric disturbances?

1.1.1.1.4.3.1
What changes occur in the digestion of carbohydrates, and what secretory changes are primarily responsible?

1.1.1.1.4.3.2
What changes occur in the digestion of fats, and what secretory changes are primarily responsible?

1.1.1.1.4.3.3
What changes occur in the digestion of proteins, and what secretory changes are primarily responsible?

1.1.1.1.4.3.4
What changes occur in salivary digestion, and what effects will the changes have on the utilization of carbohydrates?

1.1.1.1.4.3.5
What changes occur in the general digestion of foodstuffs, and how are these changes related to changes in gastric secretion?

1.1.1.1.4.3.6
What changes occur in the general intestinal digestion of foodstuffs, and how are these changes related to changes in pancreatic, bile, and intestinal secretions?

1.1.1.1.4.4.1
What changes occur in absorption of substances from the stomach, and how are these changes related to changes in gastric digestion and emptying?

1.1.1.1.4.4.2
What changes occur in the intestinal absorption of water and electrolytes, and what are the mechanisms associated with the changes?

1.1.1.1.4.4.3
What changes occur in the absorption of water and electrolytes from the colon, and what are the mechanisms associated with the changes?

1.1.1.1.4.4.4
What changes occur in the intestinal absorption of carbohydrates, and what are the mechanisms associated with the changes?

1.1.1.1.4.4.5
What changes occur in the intestinal absorption of fats, and what are the mechanisms associated with the changes?

1.1.1.1.4.4.6
What changes occur in the intestinal absorption of protein, and what are the mechanisms associated with the changes?

1.1.1.1.4.6.1
What changes occur in the accumulation of gas in the stomach, and are the changes directly related to changes in the amount of swallowed gas?

1.1.1.1.4.6.2
What changes occur in the disposition of gas in the stomach, and will the changes result in changes in eructation, borboygmi, or gastric discomfort?

1.1.1.1.4.6.3
What changes occur in the amount of gas in the colon, and do the changes result from change in swallowed gas residue or from a change in gas formed in the colon?

1.1.1.1.4.6.4
What changes occur in the disposition of gas in the colon, and will the changes result in a change in the amount and composition of flatus or feelings of abdominal discomfort?

1.1.1.1.4.7.1
What changes occur in the composition and character of the feces, and to what functions are the changes related?

1.1.1.1.4.7.2
What changes occur in the volume of the stool and the frequency of defecation, and to what functions are the changes related?

1.1.1.1.4.7.3
Do changes in the formation and release of feces necessitate any changes in the design of the waste management system?

1.1.1.1.4.8.1
What changes occur in appetite or hunger, and what are the mechanisms associated with the changes?

1.1.1.1.4.8.2
What changes occur in hunger satiation and food intake, and what are the mechanisms associated with the changes?

1.1.1.1.4.8.3
What changes occur in food preference, and can preference trends be established among the subjects?

1.1.1.1.4.8.4
What changes occur in the ad libitum intake of water, and how are the changes related to normal hydration?

1.1.1.1.4.8.5
Do changes that occur in the control of hunger and thirst necessitate changes in the size and frequency of meals and the establishment of a programmed water intake?

1.1.1.1.6.5.2
Dietary components can alter the metabolic balance, and how will the changes affect spaceflight nutritional requirements?

EARTH ORBITAL EXPERIMENT PROGRAM AND REQUIREMENTS STUDY

MANNED SPACEFLIGHT CAPABILITY

RESEARCH CLUSTER-1-BM-10
BODY FLUID ANALYSIS

C-1-40

RESEARCH CLUSTER SYNOPSIS— MANNED SPACEFLIGHT CAPABILITY

1-BM-10 Body Fluid Analysis

1. Research Objectives

The objective of this research cluster is the measurement of the biochemical composition of blood, urine, sweat, saliva, vomitus, and feces, as necessary to satisfy the analytical requirements of the other research clusters.

The research is not related to any specific NASA objective but satisfies those aspects of any objective that imply the need for the measurement of the biochemical analysis of body fluids; e.g., "Describe the qualitative and quantitative alterations evoked by spaceflight relative to hematologic, immunologic, and biochemical effects.... Assess renal and fluid / electrolyte changes.... Define the effects of spaceflight on the endocrine system...."

No critical issues were directly derived from the experiment objective. The critical issues identified in the analysis of other specific objectives were incorporated into this research cluster when their information requirements could be satisfied by a chemical analysis of body fluids. Approximately 55 critical issues were categorized in this manner.

2. Background and Current Status

The first inflight analysis of body fluids that was performed in the U.S. space research program was the analysis of the urine of the primate in Biosatellite III. Calcium, creatine, and creatinine were automatically measured by the urine collection and storage system. No onboard analysis of body fluids is scheduled to occur in Skylab A. All measurements associated with M-071 and M-073, Mineral Balance and Bio-Assay of Body Fluids, will be made on preflight and postflight blood samples and on returned samples of urine, feces, sweat, and vomitus.

The measurement capability of IMBLMS is scheduled to include laboratory analysis of blood and urine for their more important components. No information is presently available on the techniques employed for the various determinations or the degree of automation used in the analysis program. It is assumed that the laboratory will be at least semiautomated over a given series of determinations. Research and development are required not only for the various analytical techniques but also for the more general fluid handling and transfer procedures in weightlessness, which must be defined and demonstrated for space laboratory use.

3. Description of Research
A number of experiments suggested for conduct on Skylab B require blood and urine analysis as part of their protocol. These experiments are designated 1-101, 1-102, 1-108, 1-113, 1-114, 1-118, 1-121, 1-122, and 1-123 in Phase II of A Requirements Study for a Biotechnology Laboratory for Manned Earth-Orbiting Missions, NASA CR11794, and summarized in Appendix H of the present study. These experiments require the measurement of blood and urine Na, K, Cl, Ca, PO_4, proteins, and pH; complete blood counts and differential; blood gases and hemoglobin concentration; urine volume, specific gravity, and total nitrogen; plasma SGOT, SGPT, and alkaline phosphotase; plasma volume, RBC volume, and total body water; and bleeding time, clotting time, and clot retractions. All measurements are within the anticipated IMBLMS capability.

Most of the above measurements will be required for experiments recommended for conduct aboard the Space Station, with the addition of tests of lactic acid, specific plasma proteins, urine stress hormones, blood and urine glucose, urine ADH, extracellular fluid volume, plasma lipids, and liver function. Some of these measurements will require a significant increase in laboratory instrumentation and technician skill.

The methods employed in the analyses are expected to include spectrophotometry for the analysis of nonionic inorganic compounds and nonprotein nitrogenous compounds; specific ion electrodes or flame photometry for the analysis of inorganic ions; blood gas analyzer and pH electrodes for the analysis of blood gases and fluid pH; microscopy and photomicrography for the examination of samples for solids, formed elements, and particulate matter; radiation detection for the measurement of radioactive tracers; mass spectrometry for the measurement of heavy or light isotope tracers; and electrophoresis and paper chromatography for specialized measurements. It is also anticipated that all analyses would be supported by basic laboratory preparatory equipment including a clinical centrifuge, temperature-controlled mixer, timer, automatic cell counter, and chemical reagents.

For efficiency of operation, the various samples would not normally be analyzed immediately but would be allowed to accumulate until an optimum number of samples were obtained. This procedure will require the storage of samples in freezers, at temperatures of -70° C for blood and -20°C for urine.

4. Impact on Spacecraft
The clinical chemistry laboratory is expected to be a major facility of the biomedical research program, and the spacecraft must supply the space and power to accommodate the equipment associated with the laboratory. Although the weight, power, and volume requirements of the individual items of equipment are not excessive, their integration into a workable laboratory with a high degree of automation will be a major undertaking.

Experiments in space biology will require many measurements like those required by biomedicine. The two sets of requirements should be evaluated to determine the extent of facility combination that is feasible.

The laboratory should be manned by a well-trained, experienced technician. It is recommended that for this purpose the individual's primary training be in clinical chemical analysis and that he be secondarily trained as an astronaut. This constraint will impact significantly on crew requirements, particularly on missions with three crewmen.

5. Required Supporting Technology Development
Prior to the establishment of a clinical chemistry analytical laboratory aboard a spacecraft, it will be necessary to conduct the following studies, research, and development:

1. Development of fluid handling and transfer techniques. Since normal laboratory procedures are not compatible with operation in zero g, new techniques must be developed and demonstrated.

2. Trade-off studies of the advantages of onboard analysis versus returning samples to Earth. Analysis of hormones, enzymes, specific protein compounds, and other body fluid constituents are, in many cases, highly complex and difficult procedures. They are often performed in only a limited number of terrestrial laboratories. Such measurements would probably not be performed onboard. Other analyses are more equivocal. Each analysis must be carefully considered in terms of the required equipment, development, technical skill, and time for analysis; expected accuracy; difficulties anticipated in sample return; and the immediacy of the data needs.

3. Adaptation of terrestrial laboratory equipment for spacecraft use. Consideration must be given to weight, power, and volume constraints of the spacecraft, the operation of the equipment in zero-g, and the simplicity in operating the equipment in consideration of its use by an onboard technician rather than a principal investigator.

4. Automation of operations. Individual manual analysis will not be feasible within the time and space constraints of the spacecraft. A high degree of automation will be necessary if a broad spectrum of determinations is to be performed onboard.

6. References

1. Requirements Study for a Biotechnology Laboratory for Manned Earth-Orbiting Missions. NASA CR111794, 1970

2. S. P. Vinograd. Medical Aspects for an Orbiting Research Laboratory, NASA SP-86, 1966.

3. R. P. MacFate. Introduction to the Clinical Laboratory. Medical Yearbook Publishers, Inc., Chicago, 1968.

Critical Issues Addressed by Research Cluster

1-BM-10

BODY FLUID ANALYSIS

1.1.1.1.1.2.1
What changes occur in plasma volume, and what are the mechanisms associated with these changes?

1.1.1.1.1.2.2
What changes occur in total body water, and what are the mechanisms associated with these changes?

1.1.1.1.1.2.3
What changes occur in extracellular fluid volume, and what are the mechanisms associated with these changes?

1.1.1.1.1.2.4
What changes occur in RBC mass, and why do the changes occur?

1.1.1.1.1.5.1
What changes occur in blood gas transportation, and what are the mechanisms associated with these changes?

1.1.1.1.2.2.2
What changes are associated with arterial and venous oxygen and carbon dioxide tensions, and what mechanisms are associated with these changes?

1.1.1.1.2.2.3
What changes are associated with arterial and venous blood pH, and what mechanisms are associated with these changes?

1.1.1.1.2.2.4
What changes are associated with the oxygen-carrying capacity of the blood and with hemoglobin saturation

1.1.1.1.5.1.1
What changes occur in glomerular filtration, and what are the mechanisms associated with these changes?

1.1.1.1.5.1.2
What changes occur in tubular reabsorption, and what are the mechanisms associated with these changes?

1.1.1.1.5.1.3
What changes occur in tubular secretion, and what are the mechanisms associated with these changes?

1.1.1.1.5.1.4
What changes occur in total renal blood flow, and what are the mechanisms associated with these changes?

1.1.1.1.5.2.1
What changes are evident in a routine urinalysis, and can the changes be related to deleterious effects of prolonged weightlessness?

1.1.1.1.5.2.2
What changes occur in the volume, pH, and electrolyte content of the urine, and can the changes be related to changes in the body's fluid and electrolyte balance?

1.1.1.1.5.2.3
What changes occur in urine concentration by the kidney during water curtailment, and how will the volume and composition of the concentrated urine compare with that of ground-based studies?

1.1.1.1.5.2.4
What changes occur in the volume and composition of urine produced during controlled water diuresis, and how do they compare with diuresis during ground-based studies?

1.1.1.1.5.2.5
What changes occur in the volume and composition of urine produced during the administration of an osmotic diuretic, and how do they compare with ground-based experiments?

1.1.1.1.5.2.6
What changes occur in body fluid volume, distribution, and electrolyte concentration during urinary concentration and dilution?

1.1.1.1.5.4.1
What effects do changes in excretory function have on total body water?

1.1.1.1.5.4.2
What effects do changes in excretory function have on extracellular fluid volume?

1.1.1.1.5.4.3
What effects do changes in excretory function have on plasma volume?

1.1.1.1.5.4.4
What effects do changes in excretory function have on red blood-cell size (diameter)?

1.1.1.1.5.5.1
What effects do changes in excretory function have on the pH of the blood?

1.1.1.1.6.1.1.1.
What changes occur in normal blood and urine glucose levels, and how do these vary over a routine 24-hour period?

1.1.1.1.6.1.1.2
What changes occur in the response to glucose tolerance tests, and are the changes more pronounced when glucose is administered orally or intravenously?

1.1.1.1.6.1.1.5
What changes occur in the results of galactose tests, and how are the changes related to glycogen production in the liver?

1.1.1.1.6.1.2.1
What changes occur in the normal concentration and types of plasma lipids, and how are these changes related to altered lipid metabolism?

1.1.1.1.6.1.2.3
What changes occur in the respiratory quotient and in the development of ketosis during carbohydrate deprivation, and how are these changes related to ground-based experiments?

1.1.1.1.6.1.3.1
What changes occur in the results of tests commonly used to reveal malfunctions in protein metabolism and associated liver function, i.e., electrophoresis, flocculation or precipitation tests, albumin-globulin ratios, serum cholinesterase levels, etc?

1.1.1.1.6.1.3.2
What changes occur in nitrogen balance, and how are the changes related to muscular deconditioning?

1.1.1.1.6.2.2
What changes occur in the oxygen debts associated with defined metabolic loads, and what are the mechanisms associated with the changes?

1.1.1.1.6.4.1
What changes occur in the blood and urine levels of calcium and phosphorus, and serum alkaline phosphotase, and what are the mechanisms associated with the changes?

1.1.1.1.6.4.3
Do stresses such as exercise or centrifugation alter the changes in calcium-phosphorus metabolism and bone density?

1.1.1.1.6.4.4
Do changes in dietary calcium alter changes in calcium metabolism, and what is the relationship to bone density changes?

1.1.1.1.6.5.1
What changes occur in standard metabolic balance studies, and can the changes be attributed to specific changes in intermediary metabolism?

1.1.1.1.7.1.1
What changes occur in the size, color, shape and volume of the erythrocytes, and what are the mechanisms associated with the changes?

1.1.1.1.7.1.2
What changes occur in the percentage of juvenile cells, and what are the mechanisms associated with the changes?

1.1.1.1.7.1.3
What changes occur in the total number and percentage of types of leukocytes, and what are the mechanisms associated with the changes?

1.1.1.1.7.1.4
What changes occur in blood platelet count, and what are the mechanisms associated with the changes?

1.1.1.1.7.2.1
What changes occur in erythrocyte fragility, and what are the mechanisms associated with the changes?

1.1.1.1.7.2.2
What change occur in the erythrocyte production rate, and what are the mechanisms associated with the changes?

1.1.1.1.7.2.3
What changes occur in the erythrocyte life span, and what are the mechanisms associated with the changes?

1.1.1.1.7.2.4
What changes occur in the hemoglobin content and oxygen-combining capacity of the blood, and what mechanisms are associated with the changes?

1.1.1.1.7.2.5
What changes occur in the motility and phagocytic activity of the leukocytes, and what are the mechanisms associated with the changes?

1.1.1.1.7.3.1
What changes occur in clot formation in the blood; what are the mechanisms for the changes, and what is the effect on clotting time?

1.1.1.1.7.3.2
What changes occur in clot retraction; what are the mechanisms associated with the changes, and what is the effect on bleeding time?

1.1.1.1.7.3.3
What changes occur in the fibrinolytic activity of the blood; what are the mechanisms associated with the changes, and what is the effect on intravascular clotting (thrombosis)?

1.1.1.1.7.4.1
What changes occur in the total plasma albumine and globuim and the A-G ratio, and what effect will the changes have on plasma osmolarity?

1.1.1.1.7.4.2
What changes occur in plasma protein formation, and how are the changes related to protein metabolism and liver function?

1.1.1.1.7.4.3
What changes occur in plasma fibrinogen, and what is the effect on the clotting mechanisms?

1.1.1.1.7.4.4
What changes occur in the percentages of the various globulin fractions, and how will changes in α globulin affect antibody formation?

1.1.1.1.7.4.5
What changes occur in serum electrolytes, and what are the mechanisms associated with the changes?

1.1.1.1.8.1.1
What change occur in the normal blood levels of the various hormones, and how are the changes related to changes in hormone-controlled functions:

1.1.1.1.8.1.2
What changes occur in the chemical structure of the hormones synthesized by the various endocrine glands, and what effects result in hormone activity in bioassay studies?

1.1.1.1.8.3.4
What changes occur in the normal feedback relationship between endocrine activity and the blood levels of control substances other than pituitary hormones?

EARTH ORBITAL EXPERIMENT PROGRAM
AND REQUIREMENTS STUDY

MANNED SPACEFLIGHT CAPABILITY

RESEARCH CLUSTER-1-BM-12
STUDIES ON INSTRUMENTED ANIMALS

C-1-49

RESEARCH CLUSTER SYNOPSIS--MANNED SPACEFLIGHT CAPABILITY

1-BM-12 Studies on Instrumented Animals

1. Research Objectives

The objective of the research cluster is the investigation of mechanisms of changes observed in earlier experiments where the measurements require invasive techniques or are otherwise too traumatic for use on human subjects.

The experiments included in this research cluster are applicable to various physiological subdisciplines, such as cardiovascular and neurological, and consequently, are related to a number of long-range objectives in biomedicine. As a group the experiments would be responsive to an element of NASA's broad objectives in biomedicine, which is "to determine the adaptiveness and tolerance of man to space operations, including a basic understanding of the fundamental mechanisms involved."

The critical issues for this research cluster were not derived from an analysis of overall or NASA objectives. They were determined by examining the entire list of critical issues and selecting the ones best satisfied by experiments with instrumented animals.

In general, the animals referred to in this research cluster will be larger mammals, primates, cats, or dogs selected for particular characteristics required by the experiment goals. They will usually have sensors surgically implanted before flight, from which data will be received during the mission. In most cases, the animals will be returned alive for postflight studies.

2. Background and Current Status

Since the general objective of space research in biomedicine is to ensure safety and efficient performance during long-duration space missions, the most logical subject for the experiments is man himself. The information gathered is directly applicable, limited confirmation is required, and physiological changes may be easily related to changes in crew performance. As a rule, it is best that nonhuman subjects be used in biomedical experiments only when the environment or procedures are dangerous or when the techniques involved are sufficiently unpleasant to the subject. Very few of the experiments involved in establishing the existence of changes or in determining their time history are of this type. The investigation of fundamental mechanisms, however, will quite often involve invasive or traumatic procedures and, consequently, require animal subjects.

Early in the space program, when there was little knowledge of the effects of the space environment, suborbital and short orbital flights of experimental animals demonstrated that no catastrophic consequences would result from brief exposure to weightlessness, but did little to reveal the more chronic physiological changes.

The Primate Experiment of Biosatellite III was inconclusive and much additional research is necessary to verify the findings and to further investigate many of the problems that the flight revealed.

The only mammalian experiment scheduled for Skylab A is Circadian Rhythm in Pocket Mice, S-071. The results of this experiment should give information on the role of weightlessness and other aspects of the earth's environment on animal cyclical activities, but little of the data is expected to be applicable to human performance.

A thorough study of the requirements of an orbiting primate laboratory has been made by Dr. Nello Pace at the University of California, Berkeley; and various primate and small mammal space experiments and experimental techniques are being developed at Government and university laboratories throughout the Country.

3. **Description of Research**

The only research involving experimental animals recommended for Skylab B conduct in the biomedical program is the unrestrained primate experiment. This experiment is an adaption of a NASA program, Orbiting Experiment for Study of Extended Weightlessness, to the constraints of the Skylab vehicle. This experiment, often termed the Orbiting Primate Experiment (OPE) consists in exposing two rhesus monkeys to weightless spaceflight for a period of about 200 to 300 days. They will be unrestrained and minimally instrumented with only implanted temperature and ECG sensors. They will be maintained in a gaseous atmosphere with typical sea-level conditions. Social stimulation between the monkeys during the test will be provided by a "social window" between the two individual enclosures.

Inflight measurements will include television monitoring, monitoring of body temperature, heart rate, respiratory rate, activity level, and inflight behavioral assessment. Following the flights, the animals will be returned to Earth. One monkey will be immediately sacrificed and subjected to extensive histochemical and histopathological examination; the other will be maintained in a ground simulator to monitor recovery and long-term effects. The second primate will eventually be sacrified and studied in comparison with the first.

This experiment is designated 1-130 and is detailed in Phase II of A Requirements Study for a Biotechnology Laboratory for Manned Earth-Orbiting Missions, NASA CR11794, and summarized in Appendix H of this report.

The use of instrumented animals for a study of fundamental mechanisms appeared to be most applicable to the areas of cardiovascular research and neurophysiological research. Changes in these areas may be predicted from previous observations or on good theoretical bases, and the potentially involved mechanisms may be reasonably hypothesized. It appears that experiments concerning the relationship of cardiac output to regional blood flow, cardiovascular reflex activity, cardiac work capacity against an induced arterial back pressure, changes in the electrical activity of higher centers, and changes in the electrical activity of the vestibular apparatus would contribute significantly to our understanding of cardiovascular and neurophysiological changes.

The research would utilize primates for most of the experiments, with dogs possibly desired for selected cardiovascular studies and cats utilized for selected nervous-system studies. The amount of background information and the experience of the principal investigator would probably be the major factors used in deciding on the animal to be used in a particular experiment.

All animals will be instrumented prior to flight, and data will be either telemetered or conducted by hardwire to onboard receivers. Crew involvement should be minimal and would be directed to the actuation of equipment for data collection at specified intervals.

The implanted sensors related to the cardiovascular research program would include an aortic flowmeter for cardiac output, a coronary flowmeter for coronary blood flow, an aortic pressure transducer for systemic arterial pressure, pulmonary pressure transducers for right heart circulatory pressure, pressure transducers in the vena cava for central venous pressure, a pressure transducer for left ventricular pressure, an occlusive cuff for the aorta, an occlusive cuff for the common carotid artery, and a carotid nerve electrode. Standard brain electrodes stereotaxically implanted will be the primary sensors for the neurophysiological research.

Some ancillary measurements, such as those of heart rate, blood pressure, and blood analysis, will be performed in conjunction with the primary measurements in order to define the physiological state of the subjects at the time of the experiments.

4. Impact on Spacecraft

It is anticipated that each experimental animal will be enclosed in a self-contained module, automated for food and water dispensing and waste management. The modules will produce the most significant impact on the Space Station. Each module will weigh about 300 to 500 pounds, occupy about 30 cubic feet, and require about 50 w of power, which may be reduced to 20 w during the dark phase of a day-night cycle. Since the various animal modules are relatively autonomous and are not experimentally related to each other, the number that a particular spacecraft would carry would depend upon its accommodation limitations and the competition among the various disciplines for laboratory space.

Consumables associated with the experimental animals, not included in the above-mentioned module weights, would include food, about 120 gm/day/for each primate, 120 gm/per day/for each cat, and 300 gm/day/for each dog; water, about 300 gm/day/for each primate, 200 gm/per day/for each cat, and 800 gm/day/for each dog; and oxygen, 115 gm/day/for each primate, 107 gm/day/for each cat, and 265 gm/day/for each dog.

Onboard sensing equipment will be contained within the individual modules. The output will be fed into high-gain amplifiers, displayed on an oscilloscope, and recorded on magnetic tape for later analysis. Crewmen will be responsible for recording at the desired intervals and for the sequencing of data.

If earlier experiments demonstrate variable physiological changes, it will be necessary to monitor other aspects of the animal's physiological state, such as body temperature, body weight, and water balance, to correlate mechanisms with changes. Blood and urine samples may have to be taken in association with these parameters.

If feeding, watering, and waste management are not automatic, these activities would be assigned to crewmen; complete automation however, would, be desirable.

5. Required Supporting Technology Development

The various sensors discussed in the research cluster exist and are presently being used in terrestrial laboratories. Their use under the particular circumstances of the experiment, however, must be investigated. In the development of each individual experiment, the following questions must be answered:

1. Will the sensors require modification for use in the desired experiments?

2. What are the maximum number and kinds of sensors that can be implanted in a single animal before the physiological condition of the animal is compromised?

3. Is the functional life of the implanted sensor compatible with the required duration of the experiment?

Although most electrophysiological signals capable of being measured have been telemetered, a specific amplification and transmitting system would have to be designed for the particular combination of electrophysiological signals monitored in a given animal.

The module used for housing the animals would have to be designed for the particular needs of each individual experiment. Existing modules would probably be used as a point of departure for the new designs.

6. References

1. Requirements Study for a Biotechnology Laboratory for Manned Earth-Orbiting Missions. NASA CR111794

2. W. R. Adey, A. T. K. Cockett, P. B. Mack, J. P. Meehan, and N. Pace. Biosatellite III: Preliminary Findings. Science 166, October 1969, pp. 492-493.

3. Bioscience Research During Earth-Orbiting Missions: Manned Orbital Space Station. NASr-132, American Institute of Biological Sciences, December 1967.

4. N. Pace. The Automated Primate Research Laboratory. A Proposal submitted to NASA by the University of California, Berkeley, California, November 1966.

5. Orbiting Experiment for Study of Extended Weightlessness. OART, Headquarters, NASA, T-009.

Critical Issues Addressed by Research Cluster

1-BM-12

STUDIES ON INSTRUMENTED ANIMALS

1.1.1.1.1.1.1
What changes occur in the electrical activity of the heart, and what are the mechanisms associated with the changes?

1.1.1.1.1.1.2
What changes occur in the force of contraction of the heart, and what are the mechanisms associated with the changes.

1.1.1.1.1.2.5
What changes occur in the amount of blood flow through various areas, and what is the origin of the changes?

1.1.1.1.1.2.6
What changes occur in venus pressure, compliance, and stasis, and how are the changes brought about?

1.1.1.1.1.3.1
What changes occur in cardiac output, and what are the mechanisms associated with the changes?

1.1.1.1.1.3.5
What changes occur in blood pressure, and what are the mechanisms associated with the changes?

1.1.1.1.3.1.1.2
What changes occur in spatial orientation, and what illusions are associated with the changes?

1.1.1.1.3.1.1.3
What changes occur in sensitivity to linear acceleration, and what are the mechanisms associated with the changes?

1.1.1.1.3.3.1
What changes occur in the normal (alpha) rhythms associated with the resting awake state, and how are these differences manifested?

1.1.1.1.3.3.2
What changes occur in the mechanisms of "alpha blocking" associated with electroencephalographic arousal, and how are the changes related to objective manifestations of attention?

1.1.1.1.3.3.3
What changes occur in the EEG patterns associated with sleep, and how are the changes related to subjective feelings and objective evidence of sleep quality?

1.1.1.1.3.3.4
Do any EEG rhythms not included in the subject's normal patterns occur, and can these be related to personality or performance changes?

1.1.1.1.3.6.1.5
What changes occur in complex reflex patterns, and what are the mechanisms associated with the changes?

1.1.1.1.3.6.2.1
What changes occur in circulatory reflexes, and what are the mechanisms associated with the changes?

1.1.1.2.4.1
Can any of the changes observed to occur in relation to physiological deteriorations produced by prolonged exposure to zero-G be used as a trustworthy indicator of the onset of the deterioriation?

RESEARCH CLUSTER SYNOPSIS--MANNED SPACEFLIGHT CAPABILITY

1-BM-13 Effects of Weightlessness on Pulmonary Function

1. Research Objectives

The objective of the research cluster is the detection and measurement of changes in pulmonary function, the establishment of time histories for measured changes, and the measurement of associated physiological processes that will lead to a greater understanding of these changes as they are affected by weightlessness.

The research described is responsive to a long-range objective in Biomedicine, which is to "Determine the effects of spaceflight on respiratory physiological parameters." An analysis of the potential areas of pulmonary function warranting research in space resulted in the identification of 15 critical issues categorized under the headings of Pulmonary Function, Gas Exchange and Transportation, and Respiratory Control Mechanisms. The described research program supplies information requirements for these critical issues.

Changes in certain aspects of pulmonary function are transient, introduced as a respiratory compensation for a primary change in another system and disappearing when a more chronic adjustment is made. As a consequence, preflight and postflight measurements may be inadequate for the detection of all pulmonary changes occurring during flight. The parameters of interest must be observed periodically throughout the duration of the selected crew cycles to accurately assess the significance of detected changes.

2. Background and Current Status

Predictions of changes in respiratory function, including atelectasis, reductions in maximum breathing capacity, and reductions in functional residual capacity, were included in the early speculations on potential spaceflight problems. To date, however, the results of tests on the astronauts have revealed no significant problems or changes in respiratory variables. The measurements have been restricted to preflight and postflight observations of a somewhat superficial nature and, consequently, cannot be considered unequivocal evidence of continued normal function.

Ground tests involving prolonged bed rest and water immersion have, in general, shown no decrements in pulmonary functions, even when stressed with transverse accelerations similar to the Gemini reentry profile.

No experiments specifically designed to test pulmonary function are currently scheduled for conduct on Skylab A: applicable data, however, are expected to be derived from the results of experiment M-171, Metabolic Activity.

EARTH ORBITAL EXPERIMENT PROGRAM
AND REQUIREMENTS STUDY

MANNED SPACEFLIGHT CAPABILITY

RESEARCH CLUSTER—1-BM-13
EFFECTS OF WEIGHTLESSNESS ON PULMONARY FUNCTION

C-1-57

It is anticipated that the experimental equipment being considered and developed for use in Skylab B will include items permitting a large number of pulmonary function measurements.

3. Description of Research

From the results of the Skylab A program, the relationship of the rate and depth of respiration to oxygen consumption may be derived. Additonal measurements are required on subsequent flights to gain an understanding of the effects of weightlessness on pulmonary function.

An accurate respiratory flowmeter capable of measuring flow rates from 0 to 15 liters per second and integrating flows to measure lung volumes from 0 to 7 liters is currently under consideration as an item of IMBLMS instrumentation. This piece of apparatus will permit the measurement of vital capacity and its subdivisions, maximum inspiratory and expiratory flows, maximum breathing capacity, and timed vital capacity. These measurements are recommended for the second crew cycle of the Skylab B program and are described in experiment 1-107 of Phase II of A Requirements Study for a Biotechnology Laboratory for Manned Earth-Orbiting Missions, NASA CR111794, 1970, and summarized in Appendix H of the present report.

Measurements designed to reveal changes in the lung membrane, such as diffusion capacity and alveolar-arterial P_{O_2} and P_{CO_2} differences require somewhat more complex analytical procedures but remain within the anticipated capability of IMBLMS. For these measurements, arterial blood sampling is required, necessitating the participation of a physician or highly trained technician. The equipment must include an He-CO gas source and analyzer, and a blood gas analyzer. The concomitant measurement of blood pH, RBC count, and hemoglobin concentration will supplement the above tests in presenting a complete picture of the function of the blood gas transport system. This research is described in Appendix H, experiment 1-108.

The above mentioned measurements should reflect any changes that may occur in pulmonary function; to gain a complete picture of the status of the system, however, and thereby increase understanding of the nature of the changes, other measurements should be made. Because some of the techniques are difficult and quite discomforting to the subject, it was decided that they should be deferred until a large crew and more-complete spacecraft facilities are available.

The activities on the Space Station will include:

1. The measurement of residual volume of the lungs by means of the closed-circuit method, using the dilution of a known concentration and volume of helium gas after it is completely mixed with the lung gases, as the indicator of total volume.

2. The measurement of respiratory dead space by recording the time curve of nitrogen in the exhaled breath following a single breath of 100-percent O_2.

3. The measurement of lung compliance ($\Delta V/\Delta P$) as the volume change during a slow inspiration while the pressure changes are recorded from an esophageal balloon.

4. The measurement of pulmonary resistance by recording the change in trans-pulmonary pressure with changes in inspiratory flow. A pneumotachograph equipped with a flow integrator and esophageal balloon are required for this measurement.

5. Lung diffusion capacity measurements will be repeated as described in experiment 1-107. The measurements will be made independently on each of the six subjects. Compliance and resistance measurements should be performed successively while the esophageal balloon is in place.

4. Impact on Spacecraft

The various measurements described for Skylab B and the Space Station that relate to pulmonary function will produce a relatively small impact on the power, weight, and volume requirements. The major items of electronic equipment are an oscillographic display weighing about 50 lb, occupying 3 cu ft, and requiring about 60 w power; and a strip chart recorder weighing 20 lb, occuping 1 cu ft and requiring 50 w. These two items, however, are not restricted to research on pulmonary function but are utilized during experiments in almost every biomedical and behavioral area. The sensing equipment required for the pulmonary function measurements will include pulmonary flowmeters and pressure transducers weighing only 1 to 2 lb, occupying 0.1 to 0.2 cu ft, and requiring 1 to 2 w. Certain gases, such as CO, He, and O_2 will also be required for inhalation in some of the tests. These gases will be contained in small cylinders, each weighing about 5 lb and occupying about 0.2 cu ft; no power will be required in their use. All gases will be measured in a mass spectrometer weighing about 7 lb, occupying 0.2 cu ft, and using 4 w of power. The mass spectrometer will also be used in many other experiments.

For both Skylab B and Space Station experiments, six subjects are desirable with three being unconditioned and three involved in a conditioning program for potential therapeutic use. Since most of the measurements will be made to detect unanticipated changes, however, the requirement for conditioned subjects is not rigorous.

Most operations are standard laboratory procedures and can be performed by a trained medical or physiological technician.

In addition to the experiments directly concerned with measuring pulmonary function, the experiments on hypoxia, hypercapnia, and hyperthermia described in 1-BM-6, Effects of Weightlessness on Stress Responses, should result in a large amount of information on the activity of the compensatory reflexes of the respiratory system.

5. Required Supporting Technology Development
The equipment commonly used in terrestrial, pulmonary function laboratories includes bulky, gravity-dependent spirometers and other items not suitable for spacecraft use. Pulmonary flow-meters capable of measuring flows and volumes with approximately the same accuracy will be required as substitutes for the spirometers. Such equipment is understood to be presently considered within the IMBLMS program. The use of an esophogeal balloon for the measurement of intrathoracic pressures has poor subject acceptance, and substitute methods should be developed. The measurement of gas concentration by means of a single, accurate, rapidly responding spectrometer is highly desirable. It is understood that such an instrument acceptable for spacecraft use is also conceived as part of the IMBLMS program.

Before the research identified in this experiment group is conducted, carefully controlled ground experiments are required for the development and refinement of techniques and procedures.

6. References

1. C. F. Consolazio, R. E. Johnson, and L. J. Pecors. Physiological Measurements of Metabolic Functions in Man. McGraw Hill Book Co., New York, 1963.

2. S. P. Vinograd. Medical Aspects of an Orbiting Research Laboratory, NASA SP-86, 1966.

3. U. C. Luft. Aviation Physiology--The Effects of Altitude in the Handbook of Physiology, Sec. 3: Respiration, Vol. II. American Physiological Society, Washington, D. C., 1965.

4. H. G. Clamann. Space Physiology in the Handbook of Physiology, Sec. 3: Respiration, Vol. II. American Physiological Society, Washington, D. C., 1965.

Critical Issues Addressed by Research Cluster

1-BM-13

EFFECTS OF WEIGHTLESSNESS ON PULMONARY FUNCTION

1.1.1.1.1.5.1
What changes occur in blood gas transportation, and what are the mechanisms associated with the changes?

1.1.1.1.2.1.1
What changes occur in vital capacity and its components, and what mechanisms are associated with the changes?

1.1.1.1.2.1.2
What changes occur in residual volume, and what mechanisms are associated with the changes?

1.1.1.1.2.1.3
What changes occur in dead-space volume, and what mechanisms are associated with the changes?

1.1.1.1.2.1.4
What changes occur in inspiratory and expiratory flows and pressures, and what mechanisms are associated with the changes?

1.1.1.1.2.1.5
What changes occur in lung compliance, and what mechanisms are associated with the changes?

1.1.1.1.2.1.6
What changes occur in normal pulmonary ventilation, and what mechanisms are associated with the changes?

1.1.1.1.2.1.7
What changes occur in normal respiratory rate, and what mechanisms are associated with the changes?

1.1.1.1.2.2.1
What changes occur in the alveolar gas contents, and what mechanisms are associated with the changes?

1.1.1.1.2.2.2
What changes are associated with arterial and venous oxygen and carbon dioxide tensions, and what mechanisms are associated with the changes?

1.1.1.1.2.2.3
What changes are associated with arterial and venous blood pH, and what mechanisms are associated with the changes?

1.1.1.1.2.2.4
What changes are associated with the oxygen-carrying capacity of the blood and with hemoglobin saturation?

1.1.1.1.2.3.1
What changes occur in breath-holding time, and what mechanisms are associated with the changes?

1.1.1.1.7.2.4
What changes occur in the hemoglobin content and oxygen-combining capacity of the blood, and what mechanisms are associated with the changes?

1.1.1.2.4.2
Can the variables normally measured in a routine physical examination still be used as indicators of the general health of the subject after prolonged exposure to zero-G?

EARTH ORBITAL EXPERIMENT PROGRAM
AND REQUIREMENTS STUDY

MANNED SPACEFLIGHT CAPABILITY

RESEARCH CLUSTER—1-BM-14
EFFECTS OF WEIGHTLESSNESS ON METABOLISM

C-1-63

RESEARCH CLUSTER SYNOPSIS--MANNED SPACEFLIGHT CAPABILITY

1-BM-14 Effects of Weightlessness on Metabolism

1. Research Objectives

The objective of the research cluster is the investigation of energy metabolism and intermediary metabolism to determine whether changes are produced during long-duration exposure to weightlessness.

No specific long-range NASA objective deals particularly with the effects of weightlessness on metabolism. The biochemical manifestations of metabolism and electrolyte changes are found in different specific objectives. An analysis of the potential areas of metabolic function warranting research in space resulted in seven research categories: Energy Metabolism, Muscle Size and Strength, Calcium Phosphorus Metabolism, Metabolic Balance, Carbohydrate Metabolism, Fat Metabolism, and Protein Metabolism. Only the last three and some elements of energy metabolism are included in the present research cluster; the other categories are discussed elsewhere. In the four included research categories, 35 critical issues were identified.

Changes in metabolism may be manifested in numerous ways, including changes in muscle size and strength as a result of an altered protein metabolism and changes in bone density as a result of alterations in calcium metabolism. It will be necessary throughout the program to relate an observed change to a potentially more-basic metabolic change.

2. Background and Current Status

Other than some apparent changes in energy metabolism discussed more fully in 1-BM-6, Effects of Weightlessness on Stress Response, no findings have been reported on significant changes in metabolic function although such changes are implicated in muscular deconditioning and in bone decalcification. The potentially involved metabolic changes are certainly worthy of investigation because of their control over numerous vital characteristics of physiological function.

Two experiments, which are scheduled for Skylab A, should significantly increase our knowledge on the effects of weightlessness on metabolism. M-071 and M-073, Mineral Balance and Bio-Assay of Body Fluids, will examine metabolic function as manifested by changes in blood and urine constituents. M-171, Metabolic Activity, will examine energy metabolism during specified workloads, including measurements of the respiratory quotient (RQ), giving information on changes in the metabolic substrate used during working metabolism in weightlessness. In

M-071 and M-073, urine will be collected throughout the mission, which should give an indication of the time histories of the changes. Blood will be sampled preflight and postflight only.

The development of IMBLMS will permit a much greater number of onboard measurements to be made and will result in the conduct of more-detailed experiments in the area of metabolic function.

3. Description of Research

It is anticipated that because of the limited research facilities aboard Skylab A and the relatively short duration of the crew cycles, much of the research conducted during the program will require subsequent verification, more data points for trend definition, and experimental answers to questions either not investigated during Skylab A or introduced as a result of the research. The experimental program recommended for Skylab B will be confined to the investigation of the more pronounced and important areas of metabolic function.

Experiments are included to establish the time history of reduction in exercise tolerance and the role of respiratory and cardiovascular mechanisms in the changes, the time history of bone density changes and their relationship to changes in calcium balance, and the time history of degradations in muscle size and strength and their relationship to changes in nitrogen balance. These experiments are designated 1-115, 1-116, 1-117, 1-118, 1-120, and 1-121 and are detailed in Phase II of A Requirements Study for a Biotechnology Laboratory for Manned Earth-Orbiting Missions, NASA CR111794, and are summarized in Appendix H of this report.

Further studies on energy metabolism are suggested for conduct in the Space vehicle. A study concerned with the measurement of oxygen debt on calibrated exercise was considered more applicable to the area of stress response and is consequently described in research cluster 1-BM-6. A second experiment designed to study protein and lipid utilization during carbohydrate deprivation is more directly applicable to studies of intermediary metabolism. With the normal mixed diet, the resting RQ will usually reflect the dietary composition in the utilization of food for energy production; during moderate or heavy work, the RQ reflects the change to almost complete carbohydrate utilization. Observing the same parameters during carbohydrate deprivation is a superior method of testing metabolic function and metabolic reserves.

Carbohydrate metabolism can be best examined under the stimulus of a highly concentrated glucose intake, termed the glucose tolerance test. A glucose "meal" is administered, and periodic measurements are subsequently made on the glucose concentrations of the blood and urine. This permits an accurate assessment of the body's ability to handle metabolically a glucose load and, incidentally, gives valuable information about renal function. Depending upon the results of the above test, it may be desirable to investigate the effects of insulin adminstration. This test is not a simple one and should not be performed unless previous results warrant it.

Information on lipid metabolism will be derived from the carbohydrate deprivation studies and will be supplemented by plasma lipid measurements. Change in the adipose tissue mass of the body will be observed as a corollary to lean body mass measurements made in association with protein metabolism experiments.

Information on protein metabolism in weightlessness will have been gained from the nitrogen balance studies performed in Skylab B experiment 1-118. These measurements should be repeated on a space vehicle and correlated with changes in lean body mass. Because of the difficulty of making this later measurement, it was not recommended for Skylab B, but hopefully, techniques will be available and adaptable to the greater size and sophistication of the space vehicle. A survey of changes in serum proteins requiring electrophoretic techniques may be possible on the space vehicle and would add extremely valuable data to the research clusters information contributions.

If changes are observed in protein metabolism, it would be desirable to evaluate the role of the liver in these changes since the liver is the site of most protein anabolic activity. General information on liver function may be gained from galactose tolerance and bromsulfalein excretion tests. These tests are not difficult but probably should not be performed unless changes in protein metabolism are previously observed.

The measurements described in this research cluster were included in experiments 1-209, 1-210, 1-225, and 1-226, which were suggested for space station conduct in the previously mentioned biotechnology laboratory study (NASA CR111794).

4. Impact on Spacecraft

The experiments recommended for Skylab B will include some of the heaviest equipment required in the biomedical experiment program. The bicycle ergometer will have its primary use in these experiments. It weighs about 50 lb and occupies only 4 cu ft stowed; when in use, however, it requires 20 cu ft and 10 w of power. Closely associated with the ergometer in experiments on energy metabolism is the metabolic analyzer, weighing 40 lb, occupying 3 cu ft, and requiring 30 w during operation. The major requirement for nitrogen balance measurements is the weighing, drying, and stowage of feces. This places specific demands on the waste-management system and requires use of the specimen mass measurement device. The dynamometers associated with muscle strength measurements have a negligible impact, weighing only about 4 lb, occupying 1 cu ft, and requiring no power. In contradistinction, the x-ray bone densitometer weighs 100 lb, occupies about 2 cu ft, and requires about 1,000 w during its brief periods of use. Related calcium studies will be performed in the clinical chemistry laboratory.

All equipment requirements defined for Skylab B should be considered as also applying to a space vehicle. The only additions required by the specific space vehicle experiments are an increase in capabilities of the clinical chemistry laboratory to include lactic acid analysis and electrophoretic techniques for specific plasma protein determinations and the capability of measuring lean body mass. This measurement will involve the use of a body volumometer and body mass measurement for body density. A possible alternative is the measurement of lean body mass by means of total body water and whole body potassium measurements. Either approach would require extensive development for spacecraft use.

Six crewmen will serve as subjects for this research cluster. Measurements will, in general, be made twice weekly for the first 3 weeks, once weekly for the next 3 weeks, and once every 2 weeks for the cycle duration. Laboratory analyses will require a trained specialist, but most of the other observations may be made by a trained crewman.

5. Required Supporting Technology Development

The bicycle ergometer and metabolic analyzer are presently under development for the Skylab A Program. All the clinical-chemistry analytical techniques required for the Skylab B measurements are within the planned IMBLMS capability. Methods must be defined and techniques and equipment developed for lactic acid determination and plasma protein measurements suggested for a space vehicle, the latter measurement usually being performed by electrophoresis in terrestrial laboratories.

The x-ray bone densitometer should be rather easily derived from modification of existing equipment, but lean body mass will require extensive development. The most common ground-based laboratory method is the measurement of water displaced by the immersed body, which appears impractical for spacecraft use. A suggested approach would be the enclosure of the subject in a container of accurately known volume into which a known mass of helium (or other exotic gas) is injected. The volume could potentially be derived from sampling and measuring the partial pressure of helium in the gas mixture of the container ($PV = nRT$).

6. References

1. Requirements Study of a Biotechnology Laboratory for Manned Earth-Orbiting Missions. NASA CR111794, 1970

2. S. P. Vinograd. Medical Aspects of an Orbiting Research Laboratory. NASA SP-86, 1966.

3. C. F. Consolazio, R. E. Johnson, and L. J. Pecora. Physiological Measurements of Metabolic Functions in Man. McGraw Hill Book Co., New York, 1963.

4. J. Ernsting. The Metabolic Effects of Anoxia. A Textbook of Aviation Physiology. Pergamon Press, London, 1965.

Critical Issues Addressed by Research Cluster

1-BM-14

EFFECTS OF WEIGHTLESSNESS ON METABOLISM

1.1.1.1.1.4.1
What changes in normal circulatory compensatory activities are associated with exercise, and how are these changes manifested?

1.1.1.1.2.3.3
What changes in normal pulmonary ventilatory adjustments are associated with exercise?

1.1.1.1.3.6.2.3.
What changes occur in respiratory reflexes, and what are the mechanisms associated with the changes?

1.1.1.1.6.1.1.1
What changes occur in normal blood and urine glucose levels, and how will these vary over a routine 24-hour period?

1.1.1.1.6.1.1.2
What changes occur in the response to glucose tolerance tests, and are the changes more pronounced when glucose is administered orally or intravenously?

1.1.1.1.6.1.1.3
What changes occur in glucose utilization associated with exercise, and what RQ's are associated with the utilization?

1.1.1.1.6.1.1.5
What changes occur in the results of galactose tests, and how are the changes related to glycogen production in the liver?

1.1.1.1.6.1.2.1
What changes occur in the normal concentration and types of plasma lipids, and how are these changes related to altered lipid metabolism?

1.1.1.1.6.1.2.2
What changes occur in the adipose tissue mass of the crewmen, and what mechanisms are associated with the changes?

1.1.1.1.6.1.2.3
What changes occur in the respiratory quotient and in the development of ketosis during carbohydrate deprivation, and how are these changes related to ground-based experiments?

1.1.1.1.6.1.3.1
What changes occur in the results of tests commonly used to reveal malfunction in protein metabolism, and associated liver function, i.e., electrophoresis, flocculation or precipitation tests, albumin-globulin ratios, serum cholinesterase levels, etc?

1.1.1.1.6.1.3.2
What changes occur in nitrogen balance, and how are the changes related to muscular deconditioning?

1.1.1.1.6.1.3.3
What changes occur in lean body mass, and how are the changes related to muscular deconditioning?

1.1.1.1.6.1.3.4
Do any indications of edema occur with prolonged exposure to weightlessness, and can these be correlated with reductions in plasma protein levels?

1.1.1.1.6.1.3.5
What changes occur in protein metabolism during strenuous exercise, and how are the changes related to normal exercise respiratory quotients?

1.1.1.1.6.2.1
What changes occur in the metabolic cost of defined work loads in the categories of moderate, hard, and strenuous work, and to what extent are the changes related to bracing in the tractionless environment?

1.1.1.1.6.2.2
What changes occur in the accumulation of oxygen debts associated with defined metabolic loads, and what are the mechanisms associated with the changes?

1.1.1.1.6.2.3
What changes occur in the maximal oxygen consumption in weightlessness, and to what extent will the changes limit spacecraft work loads?

1.1.1.1.6.2.4
What changes occur in standard physical fitness measurements, and how are the changes related to muscular deconditioning?

1.1.1.1.6.3.1
What changes occur in dynomometer measurements of various muscles, and what is the relationship of the changes to changes in protein metabolism?

1.1.1.1.6.3.2
What changes occur in muscle size in various areas of the body, and what is the relationship of the changes in protein metabolism?

1.1.1.1.6.3.3
What changes occur in the electromyogram of muscles, both at rest and during measured contractions?

1.1.1.1.6.4.1
What changes occur in the blood and urine levels of calcium and phosphorus, and serum alkaline phosphotase, and what are the mechanisms associated with the changes?

1.1.1.1.6.4.2
What changes occur in the density of various bones, and how does each correlate with the overall changes in the density of the skeletal system?

1.1.1.1.6.4.3
Do stresses such as exercise or centrifugation alter the changes in calcium-phosphorus metabolism and bone density?

1.1.1.1.6.4.4
Do changes in dietary calcium alter changes in calcium metabolism, and what is the relationship to bone density changes?

1.1.1.1.6.5.1
What changes occur in standard metabolic balance studies, and can the changes be attributed to specific changes in intermediary metabolism?

1.1.1.1.6.5.2
Can changes in dietary components alter changes in metabolic balance, and how do the changes affect spaceflight nutritional requirements?

1.1.1.3.6.1
What changes occur in the oxygen consumption and metabolic rates associated with various work loads, and what are the mechanisms associated with the changes?

1.1.1.3.6.2
What changes occur in the cardiovascular response to strenuous work, and what are the mechanisms associated with the changes?

1.1.1.3.6.3
What changes occur in the ventilatory response to strenuous work, and what changes occur in the composition of alveolar gases?

1.1.1.3.6.4
What changes occur in maximal oxygen consumption, and what are the mechanisms associated with the changes?

1.1.1.3.6.5
What changes occur in the oxygen debt associated with various work loads, and what is the significance of the change in exercise tolerance?

1.1.1.3.6.6
What changes occur in body temperature regulation during exercise, and what are the mechanisms associated with the changes?

1.1.1.3.6.7
Do changes in response and tolerance to strenuous exercise during prolonged weightlessness result in any modifications to work load limitations imposed on the spacecraft crew?

EARTH ORBITAL EXPERIMENT PROGRAM
AND REQUIREMENTS STUDY

MANNED SPACEFLIGHT CAPABILITY

RESEARCH CLUSTER—1-BM-15
CENTRIFUGE STUDIES

C-1-71

RESEARCH CLUSTER SYNOPSIS—MANNED SPACEFLIGHT CAPABILITY

1-BM-15 Centrifuge Studies

1. Research Objectives
The objective of the research cluster is the determination of changes occurring in cardiovascular, respiratory, and vestibular responses to acceleration and rotation and to determine the usefulness of the centrifuge as a conditioning device.

The research described in this cluster is responsive to elements of four specific, long-range NASA objectives in biomedicine to perform the following:

1. Determine the extent of, and develop methods for, assessing cardiovascular adaptation to acceleration, weightlessness, and artificial-subgravity states.

2. Investigate and evaluate the effects of spaceflight on neurophysiological function, including equilibrium, coordination, sleep, alertness, biorhythms, and visual and other special senses.

3. Assure that human (biodynamic) tolerance limits for acceleration, vibration, and noise are defined for specific missions.

4. Define and develop predictive, diagnostic and therapeutic procedures, medications, and equipment to maintain the health and well being of the crew.

The critical issues were derived by examining the group of issues derived from an analysis of each of the above objectives and selecting those that were appropriate to centrifuge testing. Eighteeen critical issues were selected including cardiovascular acceleration compensation, canal sickness, angular acceleration sensitivity, oculogyral illusions, precision of movement, rotational orientation, centrifuge countermeasures, and acceleration tolerance. The des-described research program supplies information requirements for these critical issues.

To meet the above-listed objectives, the centrifuge program program must include both high angular velocities and angular accelerations to investigate acceleration tolerances, and low angular veolocities to investigate responses responses similar to those anticipated on rotating space stations.

2. **Background and Current Status**

The concept of using an onboard centrifuge for testing experimental subjects in space and for the prevention of deconditioning in weightlessness has been examined in a number of ground-based studies, prominent among which are the McDonnell Douglas study, Biomedical Potential of a Centrifuge in an Orbiting Laboratory; the Langley Research Center study, An Examination of a Possible Flight Experiment to Evaluate an Onboard Centrifuge as a Therapeutic Device; and the General Dynamics studies, Feasibility Study of a Centrifuge Experiment for the Apollo Applications Program, and The Orbital Research Centrifuge. It is from the General Dynamics study that the information on centrifuge characteristics and the experiment program described in this research cluster is derived.

Much information of value on centrifuge characteristics and experimental approaches has also beeen contributed by studies at the various slow-rotation facilities, such as the Pensacola Slow-Rotation Room, the General Dynamics Space Station Simulator, and the Langley Research Center Rotating Vehicle Simulator.

Some of the very early and still often-quoted data on artificial gravity requirements were produced in Russian studies of rats and mice rotated at various g-levels on a small animal centrifuge aboard an airplane in zero-g parabolic flight.

The General Dynamics feasibility study indicated that placing a human centrifuge onboard a space station was a desirable and workable concept. The subject research cluster is based on the assumption that the results of the study will be implemented.

3. **Description of Research**

The experiments included in this research cluster are cardiovascular and vestibular effects of centrifugation, tolerance to reentry acceleration profiles, and establishment of an exercise conditioning regimen. These experiments were designated 1-212, 1-213, and 1-214 in Phase II of A Requirements Study for a Biotechnology Laboratory for Manned Earth Orbiting Missions, NASA CR111794. All experiments involving the use of an onboard centrifuge are recommended for conduct aboard the Space Station.

Three subjects not involved in any therapeutic conditioning program and three undergoing centrifuge conditioning will participate in the tests.

The subjects will be centrifuged four times during each test day for 20 minutes at +1.7 Gz (at heart). Two subjects will be centrifuged 3 days per week throughout the first 4 weeks, and two others will be centrifuged daily from day 19 to day 28 of the flight. The absence of evidence of deconditioning will be the criterion of program effectiveness.

Acceleration tolerance will be tested on all subjects on days 7, 14, 21 and 28, of the crew cycle. Accelerations will increase to about +6 Gz or until tolerance is reached, as determined by the grayout threshold to peripheral light. During these tests the ECG, cardiac output, leg blood volume, heart rate, and blood pressure will be measured.

During slow rotation of the centrifuge (0 to 10 rpm), various vestibular tests will be made. These will include sensitivity to angular acceleration, susceptibility to motion sickness with programmed head movements, occurrence and persistence of nystagmus and the oculogyral illustion. Otolith response by means of the oculogravic illusion and horizon localization will also be tested with the subject positioned at various degrees of pitch.

Finally, the centrifuge will serve as an excellent simulator for reentry acceleration in testing the ability of the subjects to tolerate the transverse forces associated with their return to the terrestrial environment.

The measurements made during centrifugation are all associated with other experiments. ECG will be measured with sternal electrodes, cardiac output by impedance cardiography, leg blood volume by leg plethysmography, heart rate derived from the ECG, and blood pressure with an automatic blood pressure assembly. Otolith test goggles will be employed to detect oculogyral and oculogravic illusions, and nystagmus will be measured by means of the electrooculogram.

All electrophysiological signals will be amplified within the centrifuge module and transmitted through slip rings to the data processing, display, and recording systems.

4. **Impact on Spacecraft**

The orbital research centrifuge will have the most profound impact on a Space vehicle of any piece of biomedical equipment. The centrifuge must not simply be accommodated by a Space vehicle, it will dictate its design.

The total facility equipment weight, including control station, countermomentum CMG's, and other stationary support systems is approximately 1, 720 pounds at time of launch. The maximum moment of inertia of the rotating assembly during operation is 1, 475 fps^2. The maximum momentum generated during experimentation is 7, 225 fps.

Power for all centrifuge functions is supplied by rechargeable batteries, which are integrated with the counterweight.

The structural chamber in which the entire centrifuge (including the drive unit, CMG, and control console) should have a minimum height of 9 ft, a minimum diameter of 20 ft, and incorporate a 42-inch-diameter passageway through the centrifuge hub.

For additional details, the reader is referred to the various General Dynamics reports associated with NASA contracts NAS1-7309, NAS1-8548, and NAS1-8751.

The items of equipment required for associated measurements are all related to other research clusters, primarily 1-BM-4 and 1-BM-7, and are discussed in those descriptions.

5. **Required Supporting Technology Development**
The above-cited General Dynamics study sets forth the most complete set of conceptual details and specifications presently available. Detailed design and production design should be implemented if the centrifuge is to be available for incorporation into the Space Station.

6. **References**

1. A Requirements Study for a Biotechnology Laboratory for Manned Earth-Orbiting Missions. NASA CR111794, 1970.

2. Convair Division of General Dynamics. Feasibility Study of a Centrifuge Experiment for the Appollo Applications Program. NASA CR-66649, CR-66650, and CR-66651; Contract NAS1-7309, March 1968.

3. Convair Division of General Dynamics. The Orbital Research Centrifuge Continued Design and Feasibility Studies. Contract NAS1-8751, July 1969.

4. W. J. White, et al. Biomedical Potential of a Centrifuge in an Orbiting Laboratory, SSD-TDR-64-209, July 1965.

5. R.W. Stone, Jr., W. Letko, and W. R. Hook. An Examination of a Possible Flight Experiment to Evaluate an Onboard Centrifuge as a Therapeutic Device. Second Symposium on the Role of the Vestibular Organs in Space Exploration, NASA SP-115, January 1966.

Critical Issues Addressed by Research Cluster

1-BM-15

CENTRIFUGE STUDIES

1.1.1.1.1.1.5
What changes occur in heart rate, and what are the mechanisms associated with the changes?

1.1.1.1.1.4.2
What changes in normal circulatory compensatory activities are associated with centrifugation ($+G_z$ acceleration)?

1.1.1.1.3.1.1.1
What changes occur in the susceptibility to motion sickness, and what are the mechanisms associated with the changes?

1.1.1.1.3.1.1.2
What changes occur in spatial orientation, and what illusions are associated with the changes?

1.1.1.1.3.1.1.3
What changes occur in sensitivity to linear acceleration, and what are the mechanisms associated with the changes?

1.1.1.1.3.1.1.4
What changes occur in the incidence of oculogravic and oculoagravic illusions associated with exposure to linear accelerations?

1.1.1.1.3.1.2.1
What changes occur in the susceptibility to motion sickness associated with rotation in zero-G, and what are the mechanisms associated with the changes?

1.1.1.1.3.1.2.2
What changes occur in sensitivity to angular acceleration, and what are the mechanisms associated with the changes?

1.1.1.1.3.1.2.3
What changes occur in the incidence and intensity of the oculogyral illusion and nystagmus during rotation in weightlessness, and what are the mechanisms associated with the changes?

1.1.1.1.3.1.2.4
What effects do the Coriolis "forces" produced by rotation in zero-G have on the precision of limb and body movements?

1.1.1.1.3.1.2.5
What changes occur in spatial orientation during rotation in zero-G, and what are the mechanisms associated with the changes?

1.1.1.1.6.4.3
Do stresses such as exercise or centrifugation alter the changes in calcium-phosphorus metabolism and bone density?

1.1.1.2.5.3.1
What centrifugation profile is most effective in preventing the occurrence of deleterious biomedical changes?

1.1.1.2.5.3.2
How much time per day must be spent in centrifugation to prevent the occurrence of deleterious biomedical changes?

1.1.1.3.4.1
What changes occur in grayout and blackout thresholds with exposure to acceleration in various directions related to mission profiles?

1.1.1.3.4.2
What changes occur in cardiovascular responses to acceleration exposures, and how are these related to cardiovascular deconditioning?

1.1.1.3.4.3
What changes occur in tidal volumes, respiratory rates, respiratory dead spaces, and maximum breathing capacities with exposure to acceleration, particularly those related to mission profiles?

1.1.1.3.4.4
Do changes in response and tolerance to acceleration necessitate any revisions in the acceptable acceleration limits normally imposed on the mission profile?

TABLE 1. LEGEND OF CODES USED IN CREW ACTIVITY MATRICES

Table 1 is an explanation of the codes used in the following matrices. The matrices summarize the inflight crew tasks required to conduct and support the research identified in the synopses.

TYPE OF ACTIVITY

0 - Not covered below

1 - Experimental subject

2 - Spacecraft operations

3 - Preexperiment equipment preparation

4 - Maintenance of equipment

5 - Conduct of experiment

6 - Evaluate intermediate results

7 - Direct observation of phenomena

8 - Data handling

9 - Communications; initiate and receive transmissions (telemetry, voice)

CREW SKILL

0 - No special skill required

1 - Medicine

2 - Biology

3 - Physiology

4 - Psychology

5 - Engineering

6 - Astronomy

7 - Physics

8 - Oceanography

9 - Forestry

10 - Agriculture

11 - Geology

12 - Meteorology

13 - Geography

14 - Cartography

15 - Hydrology

16 - Navigation

17 - Communications

18 - Radiology

19 - Instrumentation

20 - Photography

21 - Astronaut

22 - Other

Each code includes the first one or two digits describing the discipline and a second code letter describing level of skill: A for highest skill level (requires professional training with degree or advanced degree in discipline such as M. D.): B for semiprofessional, the traditional technician level requiring several years of training; C for technician level which requires some special training.

CREW ACTIVITY MATRIX (Page 1 of 3)

RESEARCH CLUSTER NO.	TASK DESCRIPTION	EXPERIMENT EQUIPMENT	TYPE OF ACTIVITY	PECULIAR ENVIRONMENTAL REQUIREMENTS	EXCLUSIVE	CREW SKILL	FREQUENCY	TASK TIME (MIN)	NO. OF CREWMEN	START	DURATION	TASK CONCURRENCY
1-BM-4 (a)	Blood Volume Changes											
(p. 1 of 3)	(1) Obtain blood samples	Syringes	3		X	3B	2/Week 1/2 Weeks	30	1	'74	3 Wks 10 Wks	
	(2) Centrifuge, samples and read hematocrits	Laboratory Centrifuge	5		X	3c	"	12	1	"	"	
	(3) Incubate cells with radioactive tag	Incubator	5			3b	"	22	1	"	"	
	(4) Add I^{125} to plasma	Prepared iodinated Albumin	5		X	3b	"	12	1	"	"	
	(5) Wash cells and recombine with plasma	Cell Washer	5		X	3b	"	60	1	"	"	
	(6) Inject tagged samples	Syringes	5		X	3b	"	30	1	"	"	
	(7) Obtain mixed blood sample	Syringes	5		X	3b	"	30	1	"	"	
	(8) Count radioactivity of samples	Radiation Detector	5			3b	"	30	1	"	"	
	(9) Administer D_2O	Duterium Oxide	5		X	3c	2/Week 1/Week	12	1	"	2 Wks 1 Wk	
	(10) Obtain urine sample	Urine Sample Collector	5		X	3c	Daily	60	1	"	3 Wks	
	(11) Measure urine specific gravity	Refractometer	5		X	3b	Daily	60	1	"	"	
	(12) Measure D_2O concentration in urine	Mass Spectrometer	5			3b	2/Week 1/Week	60	1	"	2 Wks 1 Wk	
	(13) Measure urine Na and pH	pH Meter and ion electrodes	5		X	3b	Weekly	30	1	"	3 Wks	
	(14) Measure RBC fragility	Compound Microscope	5		X	3b	1/Week 1/3 Wks.	45	1	"	3 Wks 10 Wks	
	(15) Measure body mass of subject	BMMD	5		X	3c	Daily	90	1	"	3 Wks	
	(16) Serve as subject	--------	1		X	0	2/Week 1/2 Wks.	60	6	"	3 Wks 10 Wks.	
(b)	Orthostatic Changes (1) Apply sensors to subject	ECG/VCG, blood	3		X	3b	1/2 Days 1 Per Week	96	1	"	3 Wks 10 Wks.	
	(2) Observe display of selected physiological variables (ECG, heart rate, BP, leg plethysmography, cardiac output, body core temperature, pulse wave velocity and contour).	pressure assembly impedance cardi- ogram and flow- meter.	5		X	3b	"	60	1	"	"	
	(3) Activate and monitor LBNP device	LBNP device	5			3b	1/2 Days 1/Week	90	1	'74	3 Wks 10 Wks	
	(4) Monitor displays of selected physiological variables	Oscilloscope & Os- cillographic Recorder	5		X	3b	"	90	1	"	"	
	(5) Terminate LBNP stress	LBNP device	5		X	3b	"	6	1	"	"	
	(6) Observe display of selected physiological variables	Oscilloscope & Os- cillographic Recorder	5		X	3a	"	60	1	"	"	
	(7) Obtain urine sample	Urine collector	5		X	3c	"	10	1	"	"	

CREW ACTIVITY MATRIX (Page 2 of 3)

RESEARCH CLUSTER NO.	TASK DESCRIPTION	EXPERIMENT EQUIPMENT	TYPE OF ACTIVITY	PECULIAR ENVIRONMENTAL REQUIREMENTS	EXCLUSIVE	CREW SKILL	FREQUENCY	TASK TIME (MIN)	NO. OF CREWMEN	START	DURATION	TASK CONCURRENCY
1-BM-4 (b) (p. 2 of 3)	(8) Freeze and store urine sample	Freezer (-20°C)	8			3c	1/2 Days 1/Week	180	1	'74	3 Wks 10 Wks	
	(9) Remove sensors and store equipment	———	3		X	3c	"	60	1	"	"	
	(10) Serve as subject for experiment	———	1		X	3c	"	45	6	"	"	
(c)	Changes in Cardiac Activity											
	(1) Apply sensors to subject	ECG/VCG, and	3		X	3b	1/Week	90	1	'76	13 Wks	
	(2) Record selected physiological variables (ECG, VCG, PCG electromechanical delay)	PCG	5		X	3b	"	36	1	"	"	
	(3) Remove sensors and store equipment	———	3		X	3b	"	45	1	"	"	
	(4) Attach BCG stability form	Ballisto-cardiograph	3		X	3b	"	90	1	"	"	
	(5) Monitor BCG recording	"	5		X	3b	"	60	1	"	"	
	(6) Remove and store BCG stability form	"	3		X	3b	"	45	1	"	"	
	(7) Serve as experimental subject	———	1		X	0	"	56	6	"	"	
(d)	Circulatory Response to Blood Volume Shifts											
	(1) Apply sensors and cuffs to subject	See Task (2)	3		X	3b	"	120	1	'78	3 Wks	
	(2) Observe display of measurements of selected physiological variables (leg and arm plethysmographs, blood pressure, venous pressure, ECG, heart rate).	Plethysmographs ECG/VCG, blood pressure assembly, venous pressure manometer	5		X	3b	"	60	1	"	"	
	(3) Initiate cuff activity	pressure cuffs & measure source	5		X	3b	"	12	1	"	"	
	(4) Observe display of measurements	Oscilloscope & Oscillographic recorder	5		X	3b	"	90	1	"	"	
	(5) Terminate cuff activity	———	5		X	3b	"	12	1	"	"	
	(6) Observe measurement display	———	5		X	3b	"	60	1	"	"	
	(7) Monitor performance of valsalva maneuver	———	5		X	3b	"	18	1	"	"	
	(8) Observe measurement display	———	5		X	3b	"	30	1	"	"	
	(9) Measure and record circulation time	Decholin and timer	5&8		X	3b	"	30	1	"	"	
	(10) Remove sensors and store equipment	———	3		X	3b	"	60	1	"	"	
	(11) Serve as experimental subject	———	1		X	3c	"	82	6	"	"	

CREW ACTIVITY MATRIX (Page 3 of 3)

RESEARCH CLUSTER NO.	TASK DESCRIPTION	EXPERIMENT EQUIPMENT	TYPE OF ACTIVITY	PECULIAR ENVIRONMENTAL REQUIREMENTS	EXCLUSIVE	CREW SKILL	FREQUENCY	TASK TIME (MIN)	NO. OF CREWMEN	START	DURATION	TASK CONCURRENCY
1-BM-4 (e) (p. 3 of 3)	Changes in Heart Size											
	(1) Adjust X-ray unit as necessary	X-ray unit	3		X	3b	1/Week	10	1	'80	6 Wks	
	(2) Take lateral and anterior-posterior X-rays of subject's chest.	" "	5		X	3b	"	60	1	"	"	
	(3) Develop and store film	Film developer	8			3b	"	90	1	"	"	
	(4) Serve as experimental subject	———	1		X	0	"	10	6	"	"	
(f)	Changes in Capillary Fragility											
	(1) Apply tourniquet	Rumple-Leed tourniquet	5		X	3b	1/Week	30	1	'76	6 Wks	
	(2) Observe appearance of arm	———	5		X	3b	"	30	1	"		
	(3) Remove tourniquet	———	3		X	3c	"	12	1	"		
	(4) Record data	data sheets	8		X	3b	"	30	1	"	"	
	(5) Serve as experimental subject	———	1			0	"	180	6	"		
(g)	Changes in Carotid Sinus Activity											
	(1) Apply carotid cuff	Carotid cuff	3		X	3b	2/Week	60	1	'80	3 Wks	
	(2) Apply additional sensors	ECG/VCG blood pressure assembly	3		X	3b	"	30	1	"	"	
	(3) Activate pressure reduction	Carotid cuff	5		X	3b	"	12	1	"	"	
	(4) Observe display of ECG, heart rate & blood pressure	———	5		X	3b	"	60	1	"	"	
	(5) Terminate carotid cuff pressure reduction	———	5		X	3b	"	12	1	"	"	
	(6) Remove sensors and store	———	3		X	3b	"	30	1	"	"	
	(7) Serve as experimental subject	———	1		X	3c	"	30	6	"	"	
(h)	Changes in Intraocular Blood Pressure											
	(1) Apply plethysmographic goggles	Plethysmographic Goggles	3		X	3b	"	60	1	'80	3 Wks	
	(2) Apply additional sensors	ECG/VCG & blood pressure assembly	3		X	3b	"	30	1	"	"	
	(3) Observe display of intraocular blood pressure, heart rate, and arterial blood pressure.	———	5		X	3b	"	60	1	"	"	
	(4) Remove sensors and store	———	3		X	3b	"	30	1	"	"	
	(5) Serve as experimental subject	———	1		X	3c	"	30	6	"	"	

CREW ACTIVITY MATRIX (Page 1 of 2)

RESEARCH CLUSTER NO.	TASK DESCRIPTION	EXPERIMENT EQUIPMENT	TYPE OF ACTIVITY	PECULIAR ENVIRONMENTAL REQUIREMENTS	EXCLUSIVE	CREW SKILL	FREQUENCY	TASK TIME (MIN)	NO. OF CREWMEN	START	DURATION	TASK CONCURRENCY
1-BM-5	(a) Lung Cleansing and Traumatic Injuries in Animals											
(p. 1 of 2)	1) Maintain animal colony	small animal facility	4			3c	daily	30	1	'78	6 wks	
	2) Treat lesions as specified	clinical laboratory	5		X	3b	daily	30	1	"	"	
	3) Sacrifice animals	gas chamber	5		X	3b	1/week	60	1	"	"	
	4) Freeze and preserve specimens for return	freezer (-60°C)	8		X	3b	1/week	60	1	"	"	
	(b) Radiation Tolerance in Animals											
	1) Maintain animal colony	small animal facility	4			3c	daily	30	1	'80	7 wks	
	2) Set up radiation exposure equipment	radiation source, exposure chamber	3		X	3b	once only	90	1	"	"	
	3) Place animals in exposure chamber	" "	5		X	3c	"	30	1	"	"	
	4) Initiate radiation exposure	" "	5		X	3b	"	15	1	"	"	
	5) Terminate radiation exposure	" "	5		X	3b	"	15	1	"	"	
	6) Restore equipment	---	3		X	3b	"	15	1	"	"	
	7) Obtain blood samples	clinical laboratory	5		X	3b	*	90	1	"	4 wks	
	8) Prepare and stain slides	slide processor	5		X	3b	same as 7)	180	1	"	"	
	9) Make blood counts	microscope	5		X	3b	"	150	1	"	"	
	10) Monitor colony for fatalities	animal holding facility	5		X	3c	daily	3	1	"	"	
	11) Freeze and preserve fatalities for return	freezer (-70°C)	5		X	3c	as necessary	10	1	"	"	
	12) Sacrifice, freeze and preserve survivors for return	---	5		X	3b	once only	15	1	"	-	
	13) Record data	data sheets	8		X	3b	daily	10	1	"	4 wks	
	(c) Tolerance to Toxic Contaminants in Animals											
	1) Maintain animal colony	small animal facility	4			3c	daily	30	1	"	7 wks	
	2) Set up exposure chamber	toxic exposure chamber	3		X	3b	once only	240	1	"	-	
	3) Place animals in chamber	" "	5		X	3b	once only	60	1	"	-	
	4) Introduce contaminant	specified toxic contaminants	5		X	3b	** 3 times	45	1	"	-	
	5) Monitor contaminant level and animals' health	exposure chamber	5			3b	3 times	24 hrs	1	"	-	
	6) Terminate exposure	" "	5		X	3b	3 times	30	1	"	-	
	7) Return animals to holding facility	animal holding facility	5		X	3b	once only	45	1	"	-	

*daily for first week; three times second week; twice third and fourth weeks
**three different toxic contaminants; three groups of 20 mice each, one group for each contaminant

CREW ACTIVITY MATRIX (Page 2 of 2)

RESEARCH CLUSTER NO.	TASK DESCRIPTION	EXPERIMENT EQUIPMENT	TYPE OF ACTIVITY	PECULIAR ENVIRONMENTAL REQUIREMENTS	EXCLUSIVE	CREW SKILL	FREQUENCY	TASK TIME (MIN)	NO. OF CREWMEN	START	DURATION	TASK CONCURRENCY
1-BM-5 (p. 2 of 2)												
	8) Restore exposure equipment	---	3		X	3c	once only	120	1	'80	-	
	9) Monitor colony for fatalities	animal holding facility	5		X	3c	daily	10	1	"	4 wks	
	10) Remove and preserve fatalities	freezer (-70°C)	5		X	3c	as necessary	15	1	"	"	
	11) Sacrifice, freeze and preserve survivors for return	gas chamber and freezer	5		X	3b	once only	60	1	"	"	
	12) Record data	data sheets	8		X	3b	daily	10	1	"	"	

RESEARCH CLUSTER NO.	TASK DESCRIPTION	EXPERIMENT EQUIPMENT	TYPE OF ACTIVITY	PECULIAR ENVIRONMENTAL REQUIREMENTS	EXCLUSIVE	CREW SKILL	FREQUENCY	TASK TIME (MIN)	NO. OF CREWMEN	START	DURATION	TASK CONCURRENCY
1-BM-6 (a)	Tolerance to Hypoxia											
(p. 1 of 3)	(1) Set up low O_2 breathing mixture	Gas tanks and accessories	3		X	3b	3 times per wk.	20	1	'78	3 Weeks	
	(2) Check O_2 concentration with analyzer	O_2 analyzer	3		X	3b	"	10	1	"	"	
	(3) Set up end-tidal sampler, volume recorder and on-line analyzer	Rahn end-tidal sampler & metabolic analyzer	3		X	3b	"	15	1	"	"	
	(4) Instruct subject in techniques	——	3		X	3b	Once Only	10	1	"	——	
	(5) Produce hypoxia exposure in subject	same equipment as above	5		X	3b	3 times per wk.	18	1	"	3 Weeks	
	(6) Monitor subject appearance and performance	" "	5			3b	"	60	1	"	"	take readings
	(7) Terminate exposure	" "	5		X	3b	"	12	1	"	"	
	(8) Take readings and record	kymographic recorder	8			3b	"	12	1	"	"	while monitoring
	(9) Remove records and store	"	8		X	3c	"	30	1	"	"	
	(10) Disassemble and store equipment	——	3		X	3c	"	30	1	"	"	
	(11) Serve as experimental subject	——	1		X	3c	"	20	6	"	"	
(b)	Tolerance to Hypercapnia											
	(1) Set up high CO_2 breathing mixtures	Gas tanks and accessories	3		X	3b	3 times per wk.	30	1	'78	3 Weeks	
	(2) Check CO_2 concentrations with analyzer	CO_2 analyzer	3		X	3b	"	15	1	"	"	
	(3) Set up end-tidal sampler, minute-volume recorder, and on-line CO_2 analyzer for end-tidal samples	Rahn end-tidal sampler & metabolic analyzer.	3		X	3b	"	15	1	"	"	
	(4) Set up performance task	Psychomotor Test Board	3		X	3b	"	10	1	"	"	
	(5) Expose subject to 3% CO_2 gas mixture	——	5		X	3b	"	6	1	"	"	
	(6) Monitor subject appearance and performance	——	5		X	3b	"	60	1	"	"	
	(7) Switch to 5% mixture	——	5		X	3b	"	6	1	"	"	
	(8) Monitor subject appearance and performance	——	5		X	3b	"	60	1	"	"	
	(9) Switch to 7% mixture	——	5		X	3b	"	6	1	"	"	
	(10) Monitor subject appearance and performance	——	5		X	3b	"	60	1	"	"	
	(11) Collect records and label	Kymographic recorder	8		X	3c	"	30	1	"	"	
	(12) Analyze records, record data, and store	data sheets	8		X	3b	"	180	1	"	"	

CREW ACTIVITY MATRIX (Page 2 of 3)

RESEARCH CLUSTER NO.	TASK DESCRIPTION	EXPERIMENT EQUIPMENT	TYPE OF ACTIVITY	PECULIAR ENVIRONMENTAL REQUIREMENTS	EXCLUSIVE	CREW SKILL	FREQUENCY	TASK TIME (MIN)	NO. OF CREWMEN	START	DURATION	TASK CONCURRENCY
1-BM-6 (b) (p. 2 of 3)	(13) Disassemble and store equipment	———	3		X	3c	3 times per week	30	1	'78	3 Weeks	
	(14) Serve as experimental subject	———	1		X	3c	"	60	6	"	"	
(c)	Tolerance to Hyperthermia at Rest											
	(1) Instrument subject with skin thermistors and core temperature probe	Temperature sensors	3		X	3c	"	90	1	'80	3 Weeks	
	(2) Apply ECG electrodes	ECG electrodes				3c	"	30	1	"	"	
	(3) Adjust temperature of thermal enclosure	Thermal enclosure	3		X	3c	"	120	1	"	"	
	(4) Weigh nude subject and record	BMMD	5		X	3c	"	75	1	"	"	
	(5) Monitor exposure of subject	Thermal enclosure	5		X	3b	"	360	1	"	"	
	(6) Terminate exposure	———	5		X	3b	"	30	1	"	"	
	(7) Weigh nude subject and record	BMMD	5		X	3c	"	75	1	"	"	
	(8) Remove sensors from subject	———	3		X	3c	"	30	1	"	"	
	(9) Collect records and label	kymographic recorder	8		X	3c	"	30	1	"	"	
	(10) Analyze records, record data and store	data sheets	8		X	3b	"	180	1	"	"	
	(11) Store equipment	———	3		X	3c	"	20	1	"	"	
	(12) Serve as experimental subject	———	1		X	3c	"	105	6	"	"	
(d)	Hyperthermia During Exercise											
	(1) Apply sensors to subject (skin thermistors, core temperature probe, ECG electrodes, blood pressure cuff, respiratory mask.	Temperature sensors, ECG electrodes, blood pressure cuff, respiratory mask.	3		X	3c	3 times per week	90	1	'80	3 Weeks	
	(2) Set up bicycle ergometer in thermal enclosure	Bicycle ergometer & thermal enclosure	3		X	3c	"	15	1	"	"	
	(3) Adjust workload on ergometer	Bicycle ergometer	3		X	3c	"	18	1	"	"	
	(4) Adjust temperature of thermal enclosure	Thermal enclosure	3			3c	"	40	1	"	"	
	(5) Record values of physiological variables	kymographic recorder	5		X	3b	"	30	1	"	"	
	(6) Weigh nude subject	BMMD	5		X	3c	"	75	1	"	"	
	(7) Place subject in thermal enclosure and signal start of test.	thermal enclosure	5		X	3b	"	18	1	"	"	
	(8) Monitor exercise of subject in thermal enclosure	———	5		X	3b	"	180	1	"	"	

RESEARCH CLUSTER NO.	TASK DESCRIPTION	EXPERIMENT EQUIPMENT	TYPE OF ACTIVITY	PECULIAR ENVIRONMENTAL REQUIREMENTS	EXCLUSIVE	CREW SKILL	FREQUENCY	TASK TIME (MIN)	NO. OF CREWMEN	START	DURATION	TASK CONCURRENCY
1-BM-6 (d)	(9) Terminate test	———	5		X	3b	3 times per week	30	1	'80	3 Weeks	
(p. 3 of 3)	(10) Remove subject from thermal enclosure and reweigh nude.	Thermal enclosure (BMMD)	5		X	3c	"	95	1	"	"	
	(11) Collect records and label	kymographic recorder	8		X	3c	"	30	1	"	"	
	(12) Analyze records, record data, and store.	data sheets	8		X	3b	"	180	1	"	"	
	(13) Disassemble and store equipment	———	3		X	3c	"	20	1	"	"	
	(14) Serve as experimental subject.	———	1		X	3c	"	75	6	"	"	
(e)	Oxygen Debt Accumulation with Exercise											
	(1) Obtain venous blood sample	syringes	5		X	3b	3 times per week	30	1	'78	3 Weeks	
	(2) Analyze sample for lactic acid	analytical laboratory	5		X	3a	"	30	1	"	"	
	(3) Instrument subject with sensors (ECG electrodes, blood pressure cuff, ZCG electrodes, respiratory mask).	ECG, ZCG electrodes, blood pressure cuff, respiratory mask.	3		X	3b	"	90	1	"	"	
	(4) Set up ergometer and adjust workload	bicycle ergometer	3		X	3c	"	17	1	"	"	
	(5) Record physiological variables	———	5		X	3b	"	60	1	"	"	
	(6) Monitor physiological displays during exercise.	Oscilloscope & kymographic recorder	5		X	3b	"	90	1	"	"	
	(7) Terminate exercise	———	5		X	3b	"	12	1	"	"	
	(8) Obtain venous blood sample	syringe	5		X	3b	"	30	1	"	"	
	(9) Analyze sample for lactic acid	analytical laboratory	5		X	3a	"	30	1	"	"	
	(10) Record physiological variables	———	5		X	3b	"	60	1	"	"	
	(11) Remove sensors from subject	———	3		X	3c	"	30	1	"	"	
	(12) Collect records and label	———	8		X	3c	"	30	1	"	"	
	(13) Analyze records, record data, and store	data sheets	8		X	3b	"	180	1	"	"	
	(14) Disassemble equipment and store	———	3		X	3c	"	20	1	"	"	
	(15) Serve as experimental subject.	———	1		X	3c	"	60	6	"	"	

CREW ACTIVITY MATRIX (Page 1 of 3)

RESEARCH CLUSTER NO.	TASK DESCRIPTION	EXPERIMENT EQUIPMENT	TYPE OF ACTIVITY	PECULIAR ENVIRONMENTAL REQUIREMENTS	EXCLUSIVE	CREW SKILL	FREQUENCY	TASK TIME (MIN)	NO. OF CREWMEN	START	DURATION	TASK CONCURRENCY
1-BM-7 (a)	Human Vestibular Function											
(p. 1 of 3)	1) Set up and adjust rotating litter chair	rotating litter chair	3		X	3c	once per wk	3	1	'76	6 wks	
	2) Fasten subject in chair	"	3		X	3c	"	3	1	"	"	
	3) Apply otolith test goggles (OTG's) and bite board to subject	OTG's and bite board	3		X	3c	"	5	1	"	"	
	4) Start rotation	rotating litter chair	5		X	3c	"	6	1	"	"	
	5) Adjust to desired setting	"	5		X	3c	"	12	1	"	"	
	6) Receive and relay subjects report	"	8		X	3c	"	3	1	"	"	
	7) Repeat tasks 4 through 6 five times	"	5		X	3c	"	15	1	"	"	
	8) Readjust headrest and remove OTG's	OTG's and bite board	3		X	3c	"	6	1	"	"	
	9) Start chair rotation and adjust rate	rotating litter chair	5		X	3c	"	12	1	"	"	
	10) Voice record rpm and direction	microphone and recorder	8		X	3c	"	3	1	"	"	
	11) Have subject perform head movements	---	5		X	3c	"	1	1	"	"	
	12) Receive and relay voice reports	---	8		X	3c	"	1	1	"	"	
	13) Repeat tasks 10 through 12 five times	---	5		X	3c	"	39	1	"	"	
	14) Place chair in "Upright" position and install subject	rotating litter chair	3		X	3c	"	6	1	"	"	
	15) Monitor experiment operation five times	---	5		X	3c	"	15	1	"	"	
	16) Position readout device and give magnetic pointer and reference sphere to subject	magnetic pointer & reference sphere	3		X	3c	"	1	1	"	"	
	17) Monitor and record test five times	---	5 & 8		X	3c	"	18	1	"	"	
	18) Place chair in "Right" position	rotating litter chair	3		X	3c	"	3	1	"	"	
	19) Monitor and record test five times	---	5		X	3c	"	18	1	"	"	
	20) Stow sphere, pointer and readout device	---	3		X	3c	"	3	1	"	"	
	21) Adjust chair to litter mode	---	3		X	3c	"	6	1	"	"	
	22) Adjust chair until subject reports body parallel to floor	rotating litter chair	5		X	3c	"	3	1	"	"	
	23) Record time and position	microphone and recorder	8		X	3c	"	3	1	"	"	
	24) Return litter parallel to floor and record subject's reported position	---	5 & 8		X	3c	"	3	1	"	"	
	25) Position readout device and hand subject pointer and sphere	magnetic pointer & reference sphere	3		X	3c	"	3	1	"	"	
	26) Monitor test five times	---	5		X	3c	"	6	1	"	"	

RESEARCH CLUSTER NO.	TASK DESCRIPTION	EXPERIMENT EQUIPMENT	TYPE OF ACTIVITY	PECULIAR ENVIRONMENTAL REQUIREMENTS	EXCLUSIVE	CREW SKILL	FREQUENCY	TASK TIME (MIN)	NO. OF CREWMEN	START	DURATION	TASK CONCURRENCY
1-BM-7												
(p. 2 of 3)	27) Change chair position	---	5		X	3c	once per wk	9	1	'76	6 wks	
	28) Monitor test five times	---	5		X	3c	"	18	1	"	"	
	29) Return litter to "Upright" and release subject	---	3		X	3c	"	6	1	"	"	
	30) Serve as experimental subject	---	1		X	3c	"	75	3	"	"	
(b)	EEG Patterns and Sleep											
	1) Set up performance task and instrumentation	task board and see 2)	3		X	3c	*	15	1	"	*	
	2) Apply EEG and EOG leads	EEG and EOG instrumentation	3		X	3c	*	18	1	"	*	
	3) Test signal accuracy	oscilloscope	3		X	3c	*	6	1	"	*	
	4) Place subject in bunk and connect leads	---	3		X	3c	*	15	1	"	*	
	5) Monitor signals	---	3		X	3c	*	9	1	"	*	
	6) Serve as experimental subject											
	a. Have electrodes attached	EEG and EOG electrodes	1-3		X	3c	*	6	3	"	*	
	b. Retire to bunk	---	1-3		X	3c	*	3	3	"	*	
	c. Sleep	---	1-5			3c	*	240	3	"	*	
	d. Respond to alarm	EEG analyzer and alarm	1-5		X	3c	**	1	3	"	*	
	e. Execute performance task	task board	1-5		X	3c	**	15	3	"	*	
	f. Return to bunk	---	1-5		X	3c	**	5	3	"	*	
	g. Sleep	---	1-5			3c	**	240	3	"	*	
	h. Arise and remove electrode	---	1-3		X	3c	**	10	3	"	*	
	i. Complete sleep questionnaire	questionnaire	1-3			3c	daily	5	all 6	"	mission	
(c)	EEG and Performance											
	1) Set up performance task and electroencephalographic instrumentation	task board and EEG instrumenta.	3		X	3c	2/wk 1/wk	15	1	'77	2 wks, cycle duration (11 wks)	
	2) Apply EEG leads to subject and test	oscilloscope	3		X	3c	"	9	1	"	"	"
	3) Place subject at task board and start test	task board	5		X	3c	"	6	1	"	"	"
	4) Monitor subjects performance	---	5			3c	"	75	1	"	"	"
	5) Terminate test and remove leads	---	5		X	3c	"	15	1	"	"	"

*Twice weekly for first three weeks and weekly thereafter for crew cycle duration for each crew cycle during mission.
**Once weekly for first three weeks; once every two weeks thereafter.

CREW ACTIVITY MATRIX (Page 3 of 3)

RESEARCH CLUSTER NO.	TASK DESCRIPTION	EXPERIMENT EQUIPMENT	TYPE OF ACTIVITY	PECULIAR ENVIRONMENTAL REQUIREMENTS	EXCLUSIVE	CREW SKILL	FREQUENCY	TASK TIME (MIN)	NO. OF CREWMEN	START	DURATION	TASK CONCURRENCY
1-BM-7												
(p. 3 of 3)	6) Collect records and store	---	8		X	3c	2/wk 1/wk	9	1	'77	2 wks, cycle duration (11 wks)	
	7) Disassemble equipment and store	---	3		X	3c	"	15	1	"	"	"
	8) Serve as experimental subject	---	1		X	3c	"	33	3	"	"	"
	(d) Spinal Reflex Patterns											
	1) Instruct subject	---	3		X	3a	once only	15	1	'78	--	
	2) Test cranial nerve activity	none	5		X	3a	1/wk 1/2-wks	60	1	"	4 wks, cycle duration (7 wks)	
	3) Record data	data sheets	8		X	3a	"	12	1	"	"	"
	4) Apply electromyographic (EMG) sensors and accelerometers	EMG instrumenta. & accelerometers	3		X	3b	"	60	1	"	"	"
	5) Test deep tendon reflexes	" "	5		X	3a	"	30	1	"	"	"
	6) Record observations	data sheets	8		X	3a	"	15	1	"	"	"
	7) Collect and label records	---	8		X	3c	"	9	1	"	"	"
	8) Apply EMG sensors to abdominal muscles	EMG instrumentation	3		X	3b	"	30	1	"	"	"
	9) Test superficial reflexes	" "	5		X	3a	"	30	1	"	"	"
	10) Record observations	data sheets	8		X	3a	"	12	1	"	"	"
	11) Collect and label records	---	8		X	3c	"	12	1	"	"	"
	12) Remove leads	---	3		X	3c	"	18	1	"	"	"
	13) Store records and equipment	---	3		X	3c	"	15	1	"	"	"
	14) Serve as experimental subject	---	1			0	"	45	6	"	"	"

RESEARCH CLUSTER NO. 1-BM-8

CREW ACTIVITY MATRIX (Page 1 of 2)

RESEARCH CLUSTER NO.	TASK DESCRIPTION	EXPERIMENT EQUIPMENT	TYPE OF ACTIVITY	PECULIAR ENVIRONMENTAL REQUIREMENTS	EXCLUSIVE	CREW SKILL	FREQUENCY	TASK TIME (MIN)	NO. OF CREWMEN	START	DURATION	TASK CONCURRENCY
1-BM-8 (a)	Gastrointestinal Digestion and Absorption											
(p. 1 of 2)	Subjects' Tasks: 1) Get test meal from storage	test meals	1 & 3		X	3c	3 times per day	2	3	'78	3 wks	
	2) Consume meal	---	1 & 5			3c	"	30	3	"	"	
	3) Freeze leftovers for return	freezer	1 & 5			3c	as necessary	3	3	"	"	
	4) Observe feces for evidence of dye marking	waste management system	1 & 4		X	3c	daily	1	3	"	"	
	5) Collect feces	" "	1 & 5		X	3c	"	3	3	"	"	
	6) Set up specimen mass measuring device	SMMD	1 & 3		X	3c	"	5	3	"	"	
	7) Weigh feces	SMMD	1 & 5		X	3c	"	10	3	"	"	
	8) Dry feces in fecal drying oven	waste management system	1 & 5				"	120	3	"	"	
	9) Reweigh dry feces	SMMD	1 & 5		X	3c	"	10	3	"	"	
	10) Seal and store dry feces for return	---	1 & 8		X	3c	"	2	3	"	"	
	11) Collect 24-hour urine sample	waste management system	1 & 5		X	3c	"	5	3	"	"	
	12) Measure volume	" "	1 & 5		X	3c	"	10	3	"	"	
	13) Extract aliquot	" "	1 & 5		X	3c	"	10	3	"	"	
	14) Store aliquot in freezer (-20°C) for return	freezer	1 & 8		X	3c	"	5	3	"	"	
	15) Serve as subject for blood sampling	---	1		X	3c	2 times per wk	5	3	"	"	
	16) Serve as subject for xylose test	---	1			3c	"	300	3	"	"	
	Observer's Tasks:											
	1) Obtain venous blood sample	syringes	3		X	3b	"	15	3	"	"	
	2) Freeze and store (at -70°C) sample for subsequent analysis	freezer	5		X	3c	"	6	1	"	"	
	3) Administer xylose test drink	test drink	5		X	3c	"	6	1	"	"	
	4) Receive and store subsequent (5-hr) urine samples	freezer	5		X	3c	"	15	1	"	"	
(b)	Gastric Motility and pH											
	1) Set up receivers and recorders	endoradiosonde auxillary equip.	3		X	3b	"	30	1	'80	"	
	2) Introduce endoradiosonde into subject	endoradiosonde	5		X	3b	"	30	1	"	"	
	3) Monitor passage of endoradiosonde through subject's gastrointestinal tract	---	5			3a	"	720	1	"	"	
	4) Collect records and label	---	8		X	3c	"	15	1	"	"	

CREW ACTIVITY MATRIX (Page 2 of 2)

RESEARCH CLUSTER NO.	TASK DESCRIPTION	EXPERIMENT EQUIPMENT	TYPE OF ACTIVITY	PECULIAR ENVIRONMENTAL REQUIREMENTS	EXCLUSIVE	CREW SKILL	FREQUENCY	TASK TIME (MIN)	NO. OF CREWMEN	START	DURATION	TASK CONCURRENCY
1-BM-8												
(p. 2 of 2)	5) Retrieve endoradiosonde from fecal sample	---	3		X	3b	2 times per wk	30	1	'80	3 wks	
	6) Disassemble and store quipment	---	3		X	3c	"	20	1	"	"	

CREW ACTIVITY MATRIX (Page 1 of 2)

RESEARCH CLUSTER NO.	TASK DESCRIPTION	EXPERIMENT EQUIPMENT	TYPE OF ACTIVITY	PECULIAR ENVIRONMENTAL REQUIREMENTS	EXCLUSIVE	CREW SKILL	FREQUENCY	TASK TIME (MIN)	NO. OF CREWMEN	START	DURATION	TASK CONCURRENCE
1-BM-10 (a)	Analysis for Inorganic Ions											
(p. 1 of 2)	1) Set up specific ion electrodes and recorder	ion electrode	3		X	3b	*Note	30	1	'74	Mission	
	2) Obtain samples from storage	freezer (-70°C)	3		X	3c	"	10	1	"	"	
	3) Thaw and mix samples	warmer-mixer	3			3b	"	30	1	"	"	
	4) Centrifuge samples	laboratory centrifuge	3			3b	"	15	1	"	"	
	5) Extract plasma	pipettes	3		X	3b	"	15	1	"	"	
	6) Make required dilutions	---	5		X	3b	"	15	1	"	"	
	7) Place in ion analyzer	---	5		X	3b	"	60	1	"	"	
	8) Record and store data	data sheets	8		X	3b	"	20	1	"	"	
	9) Dispose of samples	disposal	3		X	3c	"	15	1	"	"	
	10) Clean and store equipment	---	3		X	3c	"	30	1	"	"	
(b)	Analysis for Non-ionic Inorganics											
	1) Set up spectrophotometric analytical equipment	spectrophotometer	3		X	3b	"	30	1	"	"	
	2) Obtain plasma from group (a) analysis	---	3		X	3c	"	15	1	"	"	
	3) Make required dilutions	---	3		X	3b	"	15	1	"	"	
	4) Place samples in automatic analyzer	automatic analyzer	5		X	3b	"	60	1	"	"	
	5) Record and store data	data sheets	8		X	3b	"	20	1	"	"	
	6) Dispose of samples	disposal	3		X	3c	"	15	1	"	"	
	7) Clean and store equipment	---	3		X	3c	"	30	1	"	"	
(c)	Analysis for Non-protein Nitrogenous Compounds and Non-nitrogenous Organic Compounds											
	1) Repeat group (b) tasks	---	-		-	3b & c	"	185	1	"	"	
(d)	Analysis for Blood Gases and pH											
	1) Obtain whole blood samples	analysis follows sampling	3		X	3c	**Note	15	1	'76	"	
	2) Place samples in blood gas analyzer	blood gas analyzer	5		X	3b	"	15	1	"	"	
	3) Place samples in pH meter	pH meter	5		X	3b	"	15	1	"	"	
	4) Record and store data	data sheets	8		X	3b	"	10	1	"	"	
	5) Clean and store equipment	---	3		X	3c	"	15	1	"	"	

*Chemical analysis on body fluids will be performed when a sufficient number of samples have accumulated for efficient operation--the actual measurement time comprising a major portion of the total time. It is expected that analyses will be made every two to four weeks depending upon concomitant experiments.

**Blood gas and blood pH analyses should be made immediately after sampling and cannot, therefore, be allowed to accumulate. The frequency will be governed by ongoing experiments during any specific mission phase.

RESEARCH CLUSTER NO.	TASK DESCRIPTION	EXPERIMENT EQUIPMENT	TYPE OF ACTIVITY	PECULIAR ENVIRONMENTAL REQUIREMENTS	EXCLUSIVE	CREW SKILL	FREQUENCY	TASK TIME (MIN)	NO. OF CREWMEN	START	DURATION	TASK CONCURRENCY
1-BM-10 (p. 2 of 2)												
(e)	Examination for Solids, etc.											
	1) Set up compound microscope, microscope camera and light	compound microscope camera and light	3		X	3b	*Note	20	1	'74	Mission	
	2) Prepare slides of samples from group (a) analysis	microscope slides	5		X	3b	"	30	1	"	"	
	3) Stain slide	slide processor	5			3b	"	120	1	"	"	
	4) Examine under microscope	microscope	5		X	3b	"	240	1	"	"	
	5) Select area of slide	microscope	5		X	3b	"	60	1	"	"	
	6) Photograph slide	camera	5		X	3b	"	60	1	"	"	
	7) Develop and examine film	film developer	8		X	3b	"	120	1	"	"	
	8) Record microscopic data	data sheets	8		X	3b	"	30	1	"	"	
	9) Store slides and film for return	---	8		X	3c	"	20	1	"	"	
	10) Clean and store microscope	---	3		X	3b	"	20	1	"	"	
(f)	Analysis for Plasma Proteins and Amino Acids											
	1) Set up electrophoretic equipment and paper chromatographic equipment	electrophroesis apparatus and paper chromatograph	3		X	3b	"	120	1	'80	"	
	2) Obtain plasma samples from group (a) tasks	---	3		X	3c	"	15	1	"	"	
	3) React plasma sample with required reagents	reagents	5		X	3b	"	30	1	"	"	
	4) Place samples in apparatus	---	5		X	3b	"	60	1	"	"	
	5) Record data and store	data sheets	8		X	3b	"	30	1	"	"	
	6) Clean and store apparatus	---	3		X	3b	"	60	1	"	"	
(g)	Radioactive Tracer Measurement											
	1) Obtain sample from storage	---	3		X	3c	"	15	1	'74	"	
	2) Centrifuge and separate cells and plasma	laboratory centrifuge	3		X	3b	"	60	1	"	"	
	3) Make required dilutions	---	3		X	3b	"	30	1	"	"	
	4) Place in radiation detector chambers	radiation detector	5		X	3b	"	120	1	"	"	
	5) Activate detector	"	5		X	3b	"	30	1	"	"	
	6) Retrieve printout tape, label and store	"	8		X	3b	"	30	1	"	"	
	7) Dispose of samples	disposal	3		X	3b	"	60	1	"	"	
	8) Clean and shut down equipment	---	3		X	3b	"	60	1	"	"	

CREW ACTIVITY MATRIX

RESEARCH CLUSTER NO.	TASK DESCRIPTION	EXPERIMENT EQUIPMENT	TYPE OF ACTIVITY	PECULIAR ENVIRONMENTAL REQUIREMENTS	EXCLUSIVE	CREW SKILL	FREQUENCY	TASK TIME (MIN)	NO. OF CREWMEN	START	DURATION	TASK CONCURRENCE
1-BM-12	NOTE: The following tasks are common to a large number of instrumented animal experiments. The frequency of the tasks will be related to the number of experiments onboard any particular flight.											
	1) Observe status and well being of animal subject	---	4		X	3c	daily	15	1	'74		
	2) Replenish automatically dispensed food and supplies	food, water, O_2	4		X	3c	once per wk	60	1	"		
	3) Actuate receiving and recording equipment	sensing and recording equip.	3		X	3c	daily/ weekly	15	1	"	3 wks, crew cycle duration	
	4) Monitor signals and equipment operation	" "	5			3c	"	30	1	"		
	5) Terminate signal recording and experiment activities	" "	5		X	3c	"	15	1	"		
	6) Collect and examine records	" "	8		X	3c	"	10	1	"		
	7) Label and store records	---	8		X	3c	"	5	1	"		
	8) Prepare animals for return	---	3		X	3c	once only	120	1	"	--	
	NOTE: No onboard repair or replacement of implanted instruments are scheduled for the experiments in this research cluster.											

RESEARCH CLUSTER NO.	TASK DESCRIPTION	EXPERIMENT EQUIPMENT	TYPE OF ACTIVITY	PECULIAR ENVIRONMENTAL REQUIREMENTS	EXCLUSIVE	CREW SKILL	FREQUENCY	TASK TIME (MIN)	NO. OF CREWMEN	START	DURATION	TASK CONCURRENCY
1-BM-13 (a)	Changes in Lung Volumes and Breathing Mechanics											
(p. 1 of 2)	1) Set up respiratory flow meter & recording equipment	respiratory flow-meter, signal conditioner, kymographic recorder	3		X	3c	1/week 1/2-wk	15	1	'75	4 wks 9 wks	
	2) Instruct subject in techniques	---	3		X	3c	"	15	1	"	"	
	3) Obtain records of lung volumes	flowmeter and recorder	5		X	3c	"	15	1	"	"	
	4) Obtain records of breathing mechanics (timed VC, max. breath. capacity, insp. and exp. flows)	"	5		X	3c	"	30	1	"	"	
	5) Remove and store recorders	recorder	8		X	3c	"	10	1	"	"	
	6) Disassemble and store equipment	---	3		X	3c	"	10	1	"	"	
	7) Serve as experimental subject	---	1		X	0	"	20	3	"	"	
(b)	Changes in Blood Gas Transportation											
	1) Obtain venous blood sample	syringes	3		X	3b	"	15		'76	"	
	2) Obtain arterial blood sample	syringes	3		X	3a	"	30	1	"	"	
	3) Analyze blood samples for Pa_{O_2}, Pa_{CO_2} and pH	blood gas analyzer and pH meter	5		X	3b	"	130	1	"	"	
	4) Obtain alveolar gas sample	Douglas bag	5		X	3c	"	15	1	"	"	
	5) Analyze sample for $P_{A_{O_2}}$ and $P_{A_{CO_2}}$	O_2 and CO_2 analyzers	5		X	3c	"	30	1	"	"	
	6) Analyze venous blood sample for RBC count and hemoglobin concentration	cell counter and spectrophotometer	5		X	3c	"	60	1	"	"	
	7) Measure body core temperature	temperature probe	5		X	3c	"	12	1	"	"	
	8) Serve as experimental subject	---	1		X	0	"	25	3	"	"	
(c)	Changes in Lung Diffusion Capacity											
	1) Set up He/CO gas mixture	gas mixture	3		X	3c	"	10	1	'75	4 wks	
	2) Instruct subject in techniques	---	3		X	3c	"	10	1	"	"	
	3) Obtain expired air sample following single breath of gas mixture	Douglas bag	5		X	3c	"	15	1	"	4 wks 9 wks	
	4) Analyze sample for He and CO	mass spectrometer	5		X	3c	"	30	1	"	"	
	5) Record data	data sheets	8		X	3c	"	10	1	"	"	
	6) Store equipment	---	3		X	3c	"	10	1	"	"	

CREW ACTIVITY MATRIX (Page 2 of 2)

RESEARCH CLUSTER NO.	TASK DESCRIPTION	EXPERIMENT EQUIPMENT	TYPE OF ACTIVITY	PECULIAR ENVIRONMENTAL REQUIREMENTS	EXCLUSIVE	CREW SKILL	FREQUENCY	TASK TIME (MIN)	NO. OF CREWMEN	START	DURATION	TASK CONCURRENCY
1-BM-13												
(p. 2 of 2)	7) Serve as subject	---	1		X	0	1/week 1/2-wek	15	3	'75	4 wks 9 wks	
(d)	Changes in Residual Volume											
	1) Set up equipment and He and O_2 gases	mixing chamber volume recorder	3		X	3c	"	15	1	'78	"	
		He and O_2 gases										
	2) Add He to O_2 and measure	"	3		X	3c	"	45	1	"	"	
	3) Have subject rebreathe mixture, read He concentration at minute intervals and record	He analyzer	5 & 8		X	3c	"	60	1	"	"	
	4) Remove record and store	recorder	8		X	3c	"	30	1	"	"	
	5) Disassemble and store equipment	---	3		X	3c	"	10	1	"	"	
	6) Reduce data and record	data sheets	8		X	3c	"	180	1	"	"	
	7) Serve as experimental subject	---	1		X	0	"	15	6	"	"	
(e)	Respiratory Dead Space											
	1) Set up O_2 gas, nitralyzer, and recorder	O_2 gas nitralyzer and recorder	3		X	3c	"	15	1	"	"	
	2) Instruct subject in technique	---	3		X	3c	"	30	1	"	"	
	3) Have subject take breath of O_2 and hold	---	5		X	3c	"	12	1	"	"	
	4) Have subject exhale into nitralyzer	---	5		X	3c	"	18	1	"	"	
	5) Remove record and analyze	---	8		X	3c	"	90	1	"	"	
	6) Record data	data sheets	8		X	3c	"	60	1	"	"	
	7) Store equipment	---	3		X	3c	"	15	1	"	"	
	8) Serve as subject	---	1		X	0	"	15	6	"	"	
(f)	Lung Compliance and Pulmonary Resistance											
	1) Set up equipment	manometer flowmeter	3		X	3c	"	15	1	"	"	
	2) Introduce esophageal balloon into subject esophagus	esophageal balloon	5		X	3b	"	90	1	"	"	
	3) Record flows and pressures during inspiration	"	5		X	3b	"	90	1	"	"	
	4) Remove record and store	kymographic recorder	8		X	3c	"	30	1	"	"	
	5) Store equipment	---	3		X	3c	"	15	1	"	"	
	6) Serve as experimental subject	---	1		X	3c	"	30	6	"	"	

RESEARCH CLUSTER NO.	TASK DESCRIPTION	EXPERIMENT EQUIPMENT	TYPE OF ACTIVITY	PECULIAR ENVIRONMENTAL REQUIREMENTS	EXCLUSIVE	CREW SKILL	FREQUENCY	TASK TIME (MIN)	NO. OF CREWMEN	START	DURATION	TASK CONCURRENCY
1-BM-14 (a)	Exercise Tolerance											
(page 1 of 4)	(1) Set up bicycle ergometer and metabolic analyzer.	bicycle ergometer, metabolic analyzer	3		X	3C	Once per week	15	1	'74	crew cycle	
	(2) Apply ECG leads, temperature probe and metabolic mask.	ECG leads, temperature probe and metabolic mask.	3		X	3C	"	30	1	"	"	
	(3) Seat subject on ergometer, set workload and commence recording.	bicycle ergometer	5		X	3C	"	6	1	"	"	
	(4) Observe pre-exercise recordings	bicycle ergometer	5		X	3C	"	60	1	"	"	
	(5) Signal subject to commence exercise	" "	5		X	3C	"	3	1	"	"	
	(6) Observe exercise recordings	" "	5		X	3C	"	90	1	"	"	
	(7) Signal subject to stop exercise	" "	5		X	3C	"	3	1	"	"	
	(8) Observe post-exercise recordings	" "	5		X	3C	"	60	1	"	"	
	(9) Remove leads, clean, and store.	———	3		X	3C	"	30	1	"	"	
	(10) Collect records, label, and store.	———	8		X	3C	"	10	1	"	"	
	(11) Disassemble equipment and store.	———	3		X	3C	"	15	1	"	"	
	(12) Serve as experimental subject	———	1		X	3C	"	50	6	"	"	
(b)	Mechanism of Exercise Tolerance											
	(1) Set up bicycle ergometer and metabolic analyzer.	bicycle ergometer, metabolic analyzer	3		X	3C	Once per week	15	1	'75	4 weeks	
	(2) Apply ECG leads, impedance cardiograph (ZCG) leads, temperature probe, metabolic mask.	ECG and ZCG leads, temperature probe & metabolic mask.	3		X	3C	"	45	1	"	"	
	(3) Repeat tasks "(3)" through "(11)" of Part "(a)", above.	———	3,5,8		X	3C	"	162	1	"	"	
	(4) Serve as experimental subject	———	1		X	3C	"	55	3	"	"	
(c)	Maximal Oxygen Consumption											
	(1) Set up bicycle ergometer and metabolic analyzer.	bicycle ergometer, metabolic analyzer	3		X	3C	Once per week	15	1	'75	4 weeks	
	(2) Apply ECG leads and metabolic mask	ECG leads and metabolic mask	3		X	3C	"	15	1	"	"	
	(3) Seat subject on ergometer and record pre-exercise O_2 consumption.	———	5		X	3C	"	30	1	"	"	
	(4) Adjust workload and signal subject to commence exercise.	———	5		X	3C	"	6	1	"	"	
	(5) Record O_2 consumption.	———	5		X	3C	"	9	1	"	"	

RESEARCH CLUSTER NO.	TASK DESCRIPTION	EXPERIMENT EQUIPMENT	TYPE OF ACTIVITY	PECULIAR ENVIRONMENTAL REQUIREMENTS	EXCLUSIVE	CREW SKILL	FREQUENCY	TASK TIME (MIN)	NO. OF CREWMEN	START	DURATION	TASK CONCURRENCY
1-BM-14 (c)	(6) Increase ergometer workload	———	5		X	3C	Once per week	1.5	1	'75	4 weeks	
(page 2 of 4)	(7) Record O_2 consumption	———	5		X	3C	"	9	1	"	"	
	(8) Repeat tasks "(6)" and "(7)" until O_2 consumption remains constant over two successive workloads.	———	5		X	3C	"	40	1	"	"	
	(9) Signal subject to terminate exercise.	———	5		X	3C	"	15	1	"	"	
	(10) Remove leads, clean and store.	———	3		X	3C	"	15	1	"	"	
	(11) Collect records and label	———	8		X	3C	"	10	1	"	"	
	(12) Analyze records and record data	data sheets	8		X	3C	"	180	1	"	"	
	(13) Store records and data sheets	———	8		X	3C	"	5	1	"	"	
	(14) Disassemble equipment and store	———	3		X	3C	"	15	1	"	"	
	(15) Serve as experimental subject	———	1		X	3C	"	30	3	"	"	
(d)	Muscle Size and Strength											
	(1) Measure circumference of selected muscles	tape	5		X	3C	1/2 days 1/week	21	1	'75	3 weeks crew cycle duration	
	(2) Set up dynamometers	dynamometers	3		X	3C		10	1	"	"	
	(3) Record values of muscle strength from dynamometer gages.	"	5		X	3C		18	1	"	"	
	(4) Label and store records	———	8		X	3C		5	1	"	"	
	(5) Disassemble and store dynamometers	———	3		X	3C	1/2 days 1/week	5	1	"	"	
	(6) Serve as experimental subject	———	1		X	3C	"	7	6	"	"	
(e)	Changes in Nitrogen and Calcium Balance - Subject Activities.											
	(1) Obtain test meals from storage	test meals	1-3		X	3C	3 times per day	2	3	'76	3 weeks	
	(2) Consume meal	" "	1-5			3C	"	30	3	"	"	
	(3) Label and freeze remainder of meal for return	freezer (-70°C)	1-5		X	3C	As necessary	10	3	"	"	
	(4) Collect 24-hour urine samples	waste management system.	1-5		X	3C	Daily	10	3	"	"	
	(5) Measure volume	" "	1-5		X	3C	"	10	3	"	"	
	(6) Remove aliquot, freeze (-20°C), and store frozen.	freezer (-20°C)	1-5		X	3C	"	10	3	"	"	
	(7) Collect feces	waste management system.	1-5		X	3C	"	5	3	"	"	

CREW ACTIVITY MATRIX (Page 3 of 4)

RESEARCH CLUSTER NO.	TASK DESCRIPTION	EXPERIMENT EQUIPMENT	TYPE OF ACTIVITY	PECULIAR ENVIRONMENTAL REQUIREMENTS	EXCLUSIVE	CREW SKILL	FREQUENCY	TASK TIME (MIN)	NO. OF CREWMEN	START	DURATION	TASK CONCURRENCY
1-BM-14 (e)	(8) Set up specimen mass measurement device	SMMD	1-3		X	3C	Daily	5	3	'76	3 weeks	
(page 3 of 4)	(9) Weigh wet feces	"	1-5		X	3C	"	10	3	"	"	
	(10) Dry feces and store sealed	fecal drying oven	1-5			3C	"	120	3	"	"	
	(11) Serve as subject for venous samples	———	1		X	3C	2 times per week	5	3	"	"	
	(12) Set up body mass measurement device	BMMD	1-3		X	3C	Daily	5	3	"	"	
	(13) Take body weights	BMMD	1-5		X	3C	"	10	3	"	"	
	Observer's Tasks:											
	(1) Take venous blood sample	syringes	5		X	3b	2 times per week	15	1	"	"	
	(2) Store frozen (-70°C) for subsequent analysis.	Freezer (-70°C)	5		X	3C	"	5	1	"	"	
	(3) Receive, examine, and store subject records.	———	8		X	3C	Daily	10	1	"	"	
(f)	Bone Density Changes											
	(1) Set up bone densitometer	X-ray densitometer.	3		X	3b	**NOTE BELOW:	15	1	'74	**NOTE BELOW	
	(2) X-ray calibration wedge	calibration wedge	5		X	3b	"	12	1	"	"	
	(3) X-ray selected bones		5		X	3b	"	30	1	"	"	
	(4) Remove, label, and store film	X-ray film	8		X	3C	"	10	1	"	"	
	(5) Store bone densitometer	———	3		X	3C	"	15	1	"	"	
	(6) Serve as experimental subject	———	1		X	3C	"	5	6	"	"	
(g)	Carbohydrate Metabolism											
	(1) Collect blood and urine samples	syringes	5		X	3b	***NOTE BELOW:	30	1	'78	***NOTE BELOW	
	(2) Administer glucose test meal	test meal	5		X	3C	"	18	1	"	"	
	(3) Collect venous blood samples*	syringes	5		X	3b	"	30	1	"	"	
	(4) Collect urine samples*	waste management system	5		X	3C	"	12	1	"	"	
	(5) Store samples for subsequent analysis	freezer (-70°C)	5		X	3C	"	10	1	"	"	
	(6) Serve as experimental subject	———	1			3C	"	300	6	"	"	
(h)	Fat Metabolism											
	(1) Administer low carbohydrate meals	test meal	5		X	3C	"	12	1	'80	"	
	(2) Set up metabolic analyzer	metabolic analyzer	3		X	3C	"	10	1	"	"	

* Samples are collected at 30 minutes, 1 hour, 2 hours, 3 hours, 4 hours, and 5 hours after ingestion of glucose meal.
** Measurements will be taken every two days for the first two weeks, twice weekly for the second two weeks, and weekly thereafter for the duration of the crew cycle.
*** Twice weekly for the first three weeks, once weekly for the next three weeks, and once every two weeks thereafter for the cycle duration.

CREW ACTIVITY MATRIX (Page 4 of 4)

RESEARCH CLUSTER NO. 1-BM-14

RESEARCH CLUSTER NO.	TASK DESCRIPTION	EXPERIMENT EQUIPMENT	TYPE OF ACTIVITY	PECULIAR ENVIRONMENTAL REQUIREMENTS	EXCLUSIVE	CREW SKILL	FREQUENCY	TASK TIME (MIN)	NO. OF CREWMEN	START	DURATION	TASK CONCURRENCY
1-BM-14 (h)	(3) Measure subject's $\dot{V}O_2$ and $\dot{V}CO_2$	metabolic analyzer	5		X	3C	*** NOTE BELOW	60	1	'80	***NOTE BELOW	
(page 4 of 4)	(4) Calculate RQ's and record	———	5&8		X	3C	"	60	1	"	"	
	(5) Collect venous sample	syringes			X	3C	"	30	1	"	"	
	(6) Label samples and store frozen (-70°C) for subsequent plasma lipid and protein analysis.	freezer	5		X	3C	"	15	1	"	"	
	(7) Store metabolic analyzer	———	3		X	3C	"	10	1	"	"	
	(8) Serve as experimental subject	———	1		X	3C	"	15	6	"	"	
(i)	Muscle Fatigue											
	(1) Set up dynomometers and signal timer	dynomometers	3		X	3C	"	10	1	'80	"	
	(2) Observe subject repeatedly contract muscles against dynomometer resistance.	"	5			3C	"	160	1	"	"	
	(3) Record numbers from gages	"	6		X	3C	"	12	1	"	"	
	(4) Label and store records	———	8		X	3C	"	12	1	"	"	
	(5) Disassemble and store dynomometers	———	3		X	3C	"	5	1	"	"	
	(6) Serve as experimental subject	———	1		X	3C	"	30	6	"	"	
(j)	Lean Body and Adipose Tissue Mass											
	(1) Set up body mass measurement device	BMMD	3		X	3C	"	5	1	'80	"	
	(2) Weigh subjects	BMMD	5		X	3C	"	60				
	(3) Record and store data	———	8		X	3C	"	18	1	"	"	
	(4) Set up body volumometers	body volumometer	3		X	3b	"	15	1	"	"	
	(5) Measure subjects' volumes	"	5		X	3b	"	60	1	"	"	
	(6) Record and store data	———	8		X	3C	"	18	1	"	"	
	(7) Disassemble and store equipment	———	3		X	3C	"	20	1	"	***NOTE BELOW	
	(8) Calculate lean body masses and adipose tissue masses from data.	data sheets	5&8		X	3b	"	90	1	"	"	
	(9) Serve as experimental subject.	———	1		X	3C	"	20	6	"	"	

*** Twice weekly for the first three weeks, once weekly for the next three weeks, and once every two weeks thereafter for the cycle duration.

RESEARCH CLUSTER NO.	TASK DESCRIPTION	EXPERIMENT EQUIPMENT	TYPE OF ACTIVITY	PECULIAR ENVIRONMENTAL REQUIREMENTS	EXCLUSIVE	CREW SKILL	FREQUENCY	TASK TIME (MIN)	NO. OF CREWMEN	START	DURATION	TASK CONTINGENCY
1-BM-15 (a)	Grayout Thresholds (Cardiovascular)											
(page 1 of 3)	1) Apply ECG leads, blood pressure cuff, leg plethysmograph, and impedance cardiograph (ZCG) leads to subject.	ECG, ZCG, blood pressure assembly, and leg plethysmograph	3		X	3b	1/week	60	1	'80	6 weeks	
	2) Adjust chair position and arm length of centrifuge	on-board manned centrifuge	3		X	5b	"	30	1	"	"	
	3) Adjust centrifuge speed	"			X	5b	"	15	1	"	"	
	4) Position subject in centrifuge	"	3		X	5b	"	20	1	"	"	
	5) Operate centrifuge during test	"	5		X	5b	"	16	1	"	"	
	6) Monitor subject responses during test	peripheral vision light assembly	5		X	3b	"	16	1	"	"	
	7) Terminate test	———	5		X	5b	"	20	1	"	"	
	8) Remove subject from centrifuge	———	3		X	5b	"	20	1	"	"	
	9) Remove leads from subject	———	3		X	3b	"	30	1	"	"	
	10) Collect, examine, label and store records.	———	8		X	3b	"	20	1	"	"	
	11) Serve as experimental subject	———	1		X	3C		83	2	"	"	
(b)	Re-Entry Simulation											
	1) Apply ECG leads, blood pressure cuff and respiratory mask	ECG, blood pressure assembly & respiratory analyzer	3		X	3b	1/week	80	1	'80	6 weeks	
	2) Adjust arm length and chair position	on-board centrifuge	3		X	5b	"	20	1	"	"	
	3) Adjust centrifuge acceleration program	"	3		X	5b	"	15	1	"	"	
	4) Position subject in centrifuge	"	3		X	5b	"	40	1	"	"	
	5) Operate centrifuge during test	"	5		X	5b	"	44	1	"	"	
	6) Monitor subject's responses during test.	Performance test panel	5		X	3b	"	44	1	"	"	
	7) Terminate test	———	5		X	5b	"	40	1	"	"	
	8) Remove subject from centrifuge	———	3		X	5b	"	20	1	"	"	
	9) Remove leads from subject	———	3		X	3b	"	60	1	"	"	
	10) Collect, examine, label and store records.	———	8		X	3b	"	15	1	"	"	
	11) Serve as experimental subject	———	1		X	3C	"	70	4	"	"	

CREW ACTIVITY MATRIX (Page 2 of 3)

RESEARCH CLUSTER NO.	TASK DESCRIPTION	EXPERIMENT EQUIPMENT	TYPE OF ACTIVITY	PECULIAR ENVIRONMENTAL REQUIREMENTS	EXCLUSIVE	CREW SKILL	FREQUENCY	TASK TIME (MIN)	NO. OF CREWMEN	START	DURATION	TASK [illegible]
1-BM-15 (c)	Therapeutic Support (Conditioning)											
(page 2 of 3)	1) Apply ECG leads to subject	ECG	3		X	3b	1/week 1/day	10	1	'80	9 wks 10 days	
	2) Adjust arm length and chair position of centrifuge	on-board centrifuge	3		X	5b	"	15	1	"	"	
	3) Adjust centrifuge acceleration program	"	3		X	5b	"	10	1	"	"	
	4) Position subject in centrifuge	"	3		X	5b	"	10	1	"	"	
	5) Operate centrifuge during test	"	5		X	5b	"	20	1	"	"	
	6) Monitor subject's responses during test	ECG	5		X	3b	"	20	1	"	"	
	7) Terminate test	————	5		X	5b	"	10	1	"	"	
	8) Remove subject from centrifuge	————	3		X	5b	"	5	1	"	"	
	9) Remove leads from subject	————	3		X	3b	"	5	1	"	"	
	10) Collect, examine, label and store records.	————	8		X	3b	"	10	1	"	"	
	11) Serve as first experimental subject	————	1		X	3C	1/week	60		"	9 weeks	
	12) Serve as second experimental subject	————	1		X	3C	1/day	60	1	"	10 days	
(d)	Sensitivity to Angular Acceleration											
	1) Apply ECG and EOG leads to subject	ECG & EOG	3		X	3b	1/week	20	1	'80	6 weeks	
	2) Adjust arm length and chair position of centrifuge	on-board centrifuge	3		X	5b	"	32	1	"	"	
	3) Set centrifuge acceleration program	"	3		X	5b	"	20	1	"	"	
	4) Position subject in centrifuge	"	3		X	5b	"	20	1	"	"	
	5) Monitor centrifuge operation during test	"	5		X	5b	"	60	1	"	"	
	6) Monitor subject's voice responses during test	communication sys. & light arrangement	5		X	3b	"	60	1	"	"	
	7) Terminate test	————	5		X	5b	"	20	1	"	"	
	8) Remove subject from centrifuge	————	3		X	5b	"	20	1	"	"	
	9) Remove ECG and EOG leads	————	3		X	3b	"	15	1	"	"	
	10) Collect, examine, label and store records	————	8		X	3b	"	30	1	"	"	
	11) Serve as experimental subject	————	1		X	3C		75	2	"	"	
(e)	Tolerance to Tilt Simulation											
	1) Prepare centrifuge and subject (steps same as (d) above).	same as (d) above	3		X	5b & 3b	1/week	35	2	'80	6 weeks	

CREW ACTIVITY MATRIX (Page 3 of 3)

RESEARCH CLUSTER NO.	TASK DESCRIPTION	EXPERIMENT EQUIPMENT	TYPE OF ACTIVITY	PECULIAR ENVIRONMENTAL REQUIREMENTS	EXCLUSIVE	CREW SKILL	FREQUENCY	TASK TIME (MIN)	NO. OF CREWMEN	START	DURATION	TASK CONCURRENCY
1-BM-15 (e)	2) Perform test (Steps same as (d), above).	same as (d) above	5		X	5b & 3b	1/week	54	2	'80	6 weeks	
(page 3 of 3)	3) Perform cleanup (Steps same as (d) above)	" " " "	3		X	"	"	30	2	"	"	
	4) Serve as experimental subject.	" " " "	1		X	3C	"	50	2	"	"	
(f)	Semicircular Canal Stimulation											
	1) Prepare centrifuge and subject (steps same as (d), above).	same as (d) above	3		X	5b & 3b	1/week	93	2	'80	6 weeks	
	2) Conduct test (steps same as (d), above).	" " " "	5		X	"	"	312	2	"	"	
	3) Perform cleanup (steps same as (d), above).	" " " "	3		X	"	"	35	2	"	"	
	4) Serve as experimental subject.	" " " "	1		X	3C	"	400	2	"	"	
(g)	Sensitivity to Linear Acceleration											
	1) Prepare centrifuge and subject (steps same as (d), above).	same as (d) above	3		X	5b & 3b	1/week	91	2	'80	6 weeks	
	2) Conduct test (steps same as (d), above).	" " " "	5		X	"	"	189	2	"	"	
	3) Perform cleanup (steps same as (d), above).	" " " "	3		X	"	"	55	2	"	"	
	4) Serve as experimental subject.	" " " "	1		X	3C	"	290	2	"	"	

EARTH ORBITAL EXPERIMENT PROGRAM AND REQUIREMENTS STUDY

MANNED SPACEFLIGHT CAPABILITY

RESEARCH CLUSTER—1-BR-1
SENSORY, PSYCHOMOTOR, AND COGNITIVE BEHAVIOR (5 PARTS)

C-1-103

RESEARCH CLUSTER SYNOPSIS--MANNED SPACEFLIGHT CAPABILITY

1-BR-1

Sensory, Psychomotor, and Cognitive Behavior

1. Research Objectives

This research cluster is concerned with research on man's basic capability to sense, comprehend, and react to his environment as an operator and maintainer of space systems and equipment and as a scientific investigator. It emphasizes primary behavioral capabilities such as vision, hearing, reaction time, and finger manipulations as opposed to research addressed to complex tasks in which these primary characteristics are combined. The experiment group consists of five subgroups: Vision (1-BR-1-1), Behavior Effects of Acoustic Environment (1-BR-1-2), Psychomotor (1-BR-1-3), Cognitive Capability (1-BR-1-4), and Orientation (1-BR-1-5).

The research included in this Research Cluster was derived by detailed analysis of the following NASA long-range objectives for manned spaceflight:

1. Obtain biomedical and behavioral data on man over extended periods of time, from 6 months up to 1 year in duration, and at various levels of artificial gravity.

2. Obtain biomedical, behavioral, and performance data on man and develop the techniques and protocol pertinent to the maintenance of his well being for extended periods of flight - as appropriate to planetary mission durations.

3. Investigate and evaluate the effects of space flight on neurophysiological functions including equilibrium, coordination, sleep, alertness, biorhythms, visual and other special senses.

4. Assure that human (biodynamic) tolerance limits for acceleration, vibration, and noise are defined for specific missions.

5. Determine man's individual behavior characteristics and group dynamics in space.

Subobjectives for sensory, psychomotor, and cognitive human behavior were derived by subdividing the above NASA objectives into their component parts. Further analysis led to additional subobjectives (e.g., under sensory behavior five specific subobjectives addressed to auditory, somesthetic, visual, orientation, and chemical sensing were identified). Further detailed analysis at greater levels of specificity resulted in the identification of 274 critical issues. After various filtering processes, 106 of these critical issues remained (see Table 1 of Appendix B), and it is these critical issues with which this experiment group is concerned.

Sensory, psychomotor, and cognitive behavioral patterns have very direct relation to successful manned spaceflight operations. Information on skill performance changes, the rate they take place and possible tapering off of loss rates as the length of the flight is extended, is necessary for the design of future manned space vehicles, the design of equipment used by man when accomplishing operations in space, and the design of the missions he will accomplish.

2. Background and Current Status

Extensive information is available on human sensory, psychomotor, and cognitive processes and behavior, acquired over many years of laboratory and field investigation in a terrestrial environment. This information has been summarized in many general texts and handbooks (References 2 through 7, 9) as well as in specialized texts on specific sensory, psychomotor, and cognitive functions. As with many other of man's basic functions, however, there is some question about the across-the-board application of these terrestrial data to conditions of extended spaceflight. Study groups called together to deliberate the future of manned spaceflight have been unanimous in their conclusions that direct in-space measurement of man's behavioral capabilities is required before extrapolation can be made from Earth-based experimental human capabilities data (References 7 and 8). In particular these study groups pointed out that reliable long-term data on behavior systems are limited or nonexistent because of slow response times.

Vision has been identified in analytic studies as man's primary sensory capability for space application, critical to such activities as rendezvous, approach, docking, touchdown, inspection of satellites and land targets. Information must be gathered on the effects of the unusual stresses of space and steps taken to help man adapt to these new situations. For example, as Astronaut Armstrong stepped onto the surface of the moon and moved into the shadow of the lunar module, he was unsure of his footing and spoke of the lapse of time until his eyes adapted to the darkness. Known aids to maintain the astronauts' dark adaptation levels and facilitate recovery from glare require identification, development, and test. An even greater problem is the possible continuing degradation as man extends his stay in the space environment.

Brief spaceflight experiences have shown losses of body fluids, tissue, and bone and these losses may increase as spaceflights are extended. Though detailed measurement of their impact on skill performance has not been accomplished in space, Earth experiments have shown that degradation in visual performance accompanies physiological deconditioning. Earth experiences have also shown that physiological deconditioning slows man's reaction time, degrades his coordination and general psychomotor capabilities and affects his perceptual patterns of spatial orientation. Man needs awareness of body orientation when accomplishing most tasks, and some reports of space experiences indicate that leaning backwards induces the illusion of spinning plus nausea; that bending forward will stop the illusion.

Non-test pilot Soviet cosmonauts have experienced debilitating motion sickness while U. S. astronauts with test pilot backgrounds have not experienced it as frequently or suffered to as great a degree. Detailed measurements of man's sensory, psychomotor, and cognitive performance during spaceflight have not been made. Data on the possible negative effects of weightlessness for periods in excess of 2 weeks generally are not available.

3. Description of Research
Detailed descriptions of the research contained in this research cluster are given in five experiment subgroup descriptions (1-BR-1-1, 1-BR-1-2, 1-BR-1-3, 1-BR-1-4, and 1-BR-1-5). This research should be initiated at the earliest opportunity and can be completed within a 5-year period of continuous spacecraft operation.

In conducting this research, individual testing periods will be scheduled to sample as large a population of available crewmen as possible and to allow appropriate time intervals (approximately 20 days) between tests for individual subjects. In general these tests will be self-administering and will be given in an area relatively free of distractions. The measurement techniques are quite similar to those used on Earth when vision, hearing, and psychomotor tests are administered.

The measurement parameters of interests are identified in Table 1.

A sufficient number of measurements will be made of each parameter for a large enough sample of crewmen to determine if changes take place, the course of change over time, and the existence and nature of individual differences. Physiological measurements will be obtained to determine if specific physiological indicators are correlated with observed changes. Information on performance changes will be used to develop and test various dietary and exercise programs to control and reverse performance changes. Experiment will be sequenced from determination of the rate and degree of change to the testing of remedial conditioning programs as necessary and the evolving of equipment and system changes at the man-machine interface to ensure mission success.

Table 1

SENSORY, PSYCHOMOTOR, AND COGNITIVE PARAMETERS

Sensory				
Vision	Audition	Orientation	Cognitive	Psychomotor
Acuity	Pitch discrimination	Sensing limb position and movement	Complex perceptual inputs	Limb strength
Color perception	Temporal acuity	Linear and angular acceleration	Learning	Arm-leg control of force
Depth perception	Absolute threshold	Visual, auditory, and somesthetic illusions	Recall	Fine and complex motor abilities
Brightness Threshold	Speech intelligibility		Reasoning	Gross body coordination
Glare recovery	Sound localization		Problem solving	Tracking
Dark adaptation	Discrimination of sound motion		Speaking	
Accommodation			Writing	
Field			Motor responses	
Phorias				
Critical fusion frequency				

Instrumentation for measuring parameters, consoles at which subjects will be tested, software for programming conduct of the tests, and computer capabilities for processing raw data may be furnished as part of the proposed Integrated Medical and Behavioral Laboratory Measurement System (IMBLMS) now under study by NASA.

Crew involvement in this research cluster is primarily as experimental subjects. For an adequate sample, at least six crewmen should be tested during each crew cycle in which this experimental program is being run. For a typical 90-day period, the time required per crewman as an experimental subject will total approximately 40 hours. Approximately 5 percent time is required per crewman as an experiment observer to cover those measurement sessions which are not completely self-administering.

Three experiments within this research cluster were identified and described in detail under NASA contract NAS1-9248 "Requirements Study for a Biotechnology Laboratory for Manned Earth Orbiting Missions." These were designated in that study as

2-101 Visual capabilities in weightlessness and partial gravity
2-102 Orientation capabilities in weightlessness and partial gravity
2-103 Behavioral effects of the acoustic environment

and are described briefly in Appendix H of this report.

4. Impact on Spacecraft

The major impact of this research cluster is on crew time as described above for experimental subjects. Measuring devices and apparatus to be used for this research will approximate ten cubic feet in size, weigh 250 pounds, and use 50 to 100 watts of power during testing. An exceptional requirement is the orientation research area which calls for a flight centrifuge.

Practically all of the specific research in this group must be conducted in a dedicated area of the spacecraft which is isolated from distractions, noise, and extraneous light.

5. Required Supporting Research and Technology

This research program calls for the gathering of benchmark data on subjects prior to launch. An improved, more detailed sophisticated program will be realized if orbital stresses are simulated and their effects studied experimentally prior to initiation of the flight crew's research program.

The supporting research and technology program includes study of the effects of extended exposure to simulated zero gravity on operational psychomotor task performance and auditory capabilities, and derivation of operational task oriented cognitive capability measurements obtainable on a noninterference basis which serve the dual function of obtaining data in the research cluster area of skills retention/refresher training needs.

6. References

1. Earth Orbital Experiment Program and Requirements Study, Scientific and Technological Objectives, NASA Langley Research Center, Hampton, Virginia, L13-9852, July 28, 1969.

2. S. S. Stevens, editor, Handbook of Experimental Psychology, John Wiley and Sons, New York, 1951.

3. A. Chapanis, W. R. Garner, and C. T. Morgan, Applied Experimental Psychology, John Wiley and Sons, New York, 1949.

4. R. A. McFarland, Human Factors in Air Transportation, McGraw-Hill Book Company, Inc., New York, 1953.

5. C. T. Morgan, J. S. Cook, A. Chapanis, and M. W. Lund, editors, Human Engineering Guide to Equipment Design, McGraw-Hill Book Company, Inc., New York, 1963.

6. National Research Council, A Survey Report on Human Factors in Undersea Warfare, Committee on Undersea Warfare, NRC, Washington, D.C., 1949.

7. Proceedings of the Winter Study on Uses of Manned Space Flight, 1975 to 1985, A conference held in La Jolla, California, December 6-9, 1968, Vol. I and II, NASA, Washington, D.C., 1969.

8. Space Research--Directions for the Future. Report of a study by the Space Sciences Board, Part Three. Woods Hole, Massachusetts, 1965, Space Sciences Board, NAS/NRC, Washington, D.C., February 1966.

9. Paul Webb, editor, Bioastronautics Data Book, NASA SP-3006, National Aeronautics and Space Administration, Washington, D.C., 1964.

EARTH ORBITAL EXPERIMENT PROGRAM
AND REQUIREMENTS STUDY

MANNED SPACEFLIGHT CAPABILITY

RESEARCH CLUSTER—1-BR-1-1
VISUAL EXPERIMENT

C-1-109

CRITICAL ISSUES ADDRESSED BY RESEARCH CLUSTER

1-BR-1-1

VISUAL EXPERIMENT

1.1.2.1.1.1.3.1
Will changes in visual acuity occur in long-duration space flight?

1.1.2.1.1.1.3.3
What is the course of change over time of any observed changes?

1.1.2.1.1.1.3.4
Are there significant differences between individuals in observed changes?

1.1.2.1.1.1.3.6
What physiological measurements are correlated with changes in visual acuity?

1.1.2.1.1.1.3.13
How is visual acuity affected by spacecraft dynamics (acceleration, rotation, vibration)?

1.1.2.1.1.1.3.17
Will changes occur in long-duration space flight in ability to perceive relative distances of objects at both close and far space range?

1.1.2.1.1.1.3.19
What is the course of change over time of any observed changes?

1.1.2.1.1.1.3.20
Are there significant differences between individuals in observed changes?

1.1.2.1.1.1.3.22
What physiological measurements are correlated with changes in depth perception?

1.1.2.1.1.1.3.26
How does the provision of partial gravity affect depth perception?

1.1.2.1.1.1.3.30
How is depth perception affected by spacecraft dynamics (acceleration, vibration, rotation)?

1.1.2.1.1.1.3.35
Will changes occur in long duration space flight in ability to perceive objects in the peripheral portion of the visual field?

1.1.2.1.1.1.3.37
What is the course of change over time of any observed changes?

1.1.2.1.1.1.3.38
Are there significant differences between individuals in observed changes?

1.1.2.1.1.1.3.40
What physiological measurements are correlated with changes in peripheral vision?

1.1.2.1.1.1.3.45
What is the effect of brightness and color on peripheral vision in space?

1.1.2.1.1.1.3.46
Will changes in ability to detect differences in brightness occur in long duration space flight?

1.1.2.1.1.1.3.48
What is the course of change over time of any observed changes?

1.1.2.1.1.1.3.49
Are there significant differences between individuals in observed changes?

1.1.2.1.1.1.3.51
Will changes occur in long duration space flight in ability to identify complex visual patterns in terms of time required, errors in identification, and sensitivity?

1.1.2.1.1.1.3.53
What is the course of change over time of any observed changes?

1.1.2.1.1.1.3.54
Are there significant differences between individuals in observed changes?

1.1.2.1.1.1.3.56
What physiological measurements are correlated with changes in this function?

1.1.2.1.1.1.3.61
What is the effect of various cues (e.g., position, brightness, color, shape) on ability to perform this function?

1.1.2.1.1.1.3.62
Will changes occur in long-duration space flight in ability to detect differences in color hue, saturation, and brightness?

1.1.2.1.1.1.3.64
What is the course of change over time?

1.1.2.1.1.1.3.65
Are there significant differences between individuals in observed changes?

1.1.2.1.1.1.3.66
What physiological measurements are correlated with changes in this function?

1.1.2.1.1.1.3.70
How is performance of this function affected by spacecraft dynamics (acceleration, rotation, vibration)?

1.1.2.1.1.1.3.72
Will changes occur in long-duration space flights in ability to focus on far objects after long periods of focusing on near objects?

1.1.2.1.1.1.3.74
What is the course of change over time?

1.1.2.1.1.1.3.75
Are there significant differences between individuals in observed changes?

1.1.2.1.1.1.3.76
What physiological measurements are correlated with changes in this function?

1.1.2.1.1.1.3.79
Will changes occur in dark adaptation capabilities in long-duration space flight?

1.1.2.1.1.1.3.81
What is the course of change over time?

1.1.2.1.1.1.3.82
Are there significant differences between individuals in observed changes?

1.1.2.1.1.1.3.83
What physiological measurements are correlated with changes in this function?

EARTH ORBITAL EXPERIMENT PROGRAM AND REQUIREMENTS STUDY

MANNED SPACEFLIGHT CAPABILITY

RESEARCH CLUSTER—1-BR-1-2
BEHAVIOR EFFECTS OF ACOUSTIC ENVIRONMENT

C-1-112

CRITICAL ISSUES ADDRESSED BY RESEARCH CLUSTER

1-BR-1-2

BEHAVIORAL EFFECTS OF ACOUSTIC ENVIRONMENT

1.1.2.1.1.1.1.1
Will changes occur in long-term space flight in threshold tolerance for detection of intensity and frequency of auditory stimuli?

1.1.2.1.1.1.1.3
What is the course of changes observed?

1.1.2.1.1.1.1.4
Are there significant differences between individuals in observed changes?

1.1.2.1.1.1.1.6
What physiological measurements are correlated with changes in auditory thresholds?

1.1.2.1.1.1.1.8
Will changes occur in long-term space flight in ability to detect changes in tone patterns?

1.1.2.1.1.1.1.10
What is the course of change over time of any observed changes?

1.1.2.1.1.1.1.11
What are the individual differences in observed changes?

1.1.2.1.1.1.1.14
Are there any physiological correlates of observed changes?

1.1.2.1.1.1.1.15
Will changes occur in long-term space flight in ability to locate the source of sounds?

1.1.2.1.1.1.1.17
What is the course of change over time of any changes observed?

1.1.2.1.1.1.1.18
What are the individual differences in observed changes?

1.1.2.1.1.1.1.21
Are there any physiological correlates of observed changes?

1.1.2.1.1.1.1.22
Will changes occur in long-term space flight in ability to detect direction of movement of a moving auditory stimulus?

1.1.2.1.1.1.1.24
What is the course of change over time of any observed changes?

1.1.2.1.1.1.1.25
Are there significant differences between individuals in observed changes?

1.1.2.1.1.1.1.28
Are there any physiological correlates of observed changes?

1.1.2.1.1.1.1.29
Will changes occur in long-term space flight in ability to detect duration of auditory tones presented at just above threshold?

1.1.2.1.1.1.1.31
What is the course of change over time of any observed changes?

1.1.2.1.1.1.1.32
What are the individual differences in observed changes?

1.1.2.1.1.1.1.35
What are the physiological correlates of observed changes?

EARTH ORBITAL EXPERIMENT PROGRAM AND REQUIREMENTS STUDY

MANNED SPACEFLIGHT CAPABILITY

RESEARCH CLUSTER—1-BR-1-3
PSYCHOMOTOR

C-1-114

CRITICAL ISSUES ADDRESSED BY RESEARCH CLUSTER

1-BR-1-3

PSYCHOMOTOR

1.1.2.1.1.2.1
Will changes occur in long-term space flight in time required, errors made, and sensitivity and control for perceptual motor manipulation and control functions or force production and control?

1.1.2.1.1.2.3
What is the course of change over time of any observed changes?

1.1.2.1.1.2.4
Are there significant differences between individuals in observed changes?

1.1.2.1.1.2.6
What physiological measurements are correlated with changes in this function?

1.1.2.1.1.2.12
How is this function affected by spacecraft dynamics (acceleration, rotation, vibration)?

1.1.2.1.1.2.13
How quickly will subjects learn to perform this function in orbit as effectively as they did in one G?

1.1.2.1.1.2.15
Are some psychomotor functions more difficult in space than others?

1.1.2.1.1.2.16
How is performance of this function affected by time constraints requiring performance of the function for extended periods of time (1 sec, 10 sec, 30 sec)?

1.1.2.1.1.2.17
How is performance of this function affected by differential force loads, speed of reaction, and control/display relationships?

EARTH ORBITAL EXPERIMENT PROGRAM
AND REQUIREMENTS STUDY

MANNED SPACEFLIGHT CAPABILITY

RESEARCH CLUSTER—1-BR-1-4
COGNITIVE CAPABILITY

C-1-115

CRITICAL ISSUES ADDRESSED BY RESEARCH CLUSTER

1-BR-1-4

COGNITIVE CAPABILITY

1.1.2.1.1.3.1
Will changes occur in long-term spaceflight in ability to perform cognitive functions?

1.1.2.1.1.3.3
What is the course of change over time?

1.1.2.1.1.3.4
Are there significant differences between individuals in any observed changes?

1.1.2.1.1.3.7
What physiological measurements are correlated with changes in this function?

1.1.2.1.1.3.9
How is performance of this function affected by spacecraft dynamics (acoustics, acceleration, rotation, vibration)?

EARTH ORBITAL EXPERIMENT PROGRAM
AND REQUIREMENTS STUDY

MANNED SPACEFLIGHT CAPABILITY

RESEARCH CLUSTER—1-BR-1-5
ORIENTATION

C-1-116

Critical Issues Addressed by Research Cluster

1-BR-1-5

ORIENTATION

1.1.2.1.1.1.4.1.1
Will changes occur in long-term space flight in ability to detect rotation of the whole body? (Time from onset to detection; degrees of rotation before detection.)

1.1.2.1.1.1.4.1.3
What is the course of change over time?

1.1.2.1.1.1.4.1.4
Are there significant differences between individuals in observed changes?

1.1.2.1.1.1.4.1.5
What physiological measurements are correlated with observed changes

1.1.2.1.1.1.4.1.10
How is performance of this function affected by spacecraft dynamics (acceleration, rotation, and vibration)?

1.1.2.1.1.1.4.1.11
How is performance of this function affected by rate of acceleration, rate changes, and presence or absence of visual cues?

1.1.2.1.1.1.4.1.12
Will changes occur in long-term space flight in ability to detect linear movement of the whole body? (Time from onset to detection; distance traveled before detection.)

1.1.2.1.1.1.4.1.14
What is the course of change over time?

1.1.2.1.1.1.4.1.15
Are there significant differences between individuals?

1.1.2.1.1.1.4.1.16
What physiological measurements are correlated with observed changes?

1.1.2.1.1.1.4.1.21
How is performance of this function affected by spacecraft dynamics (acceleration, rotation, and vibration)?

1.1.2.1.1.1.4.1.22
How is performance of this function affected by speed of motion, rate of onset, rate of change in velocity, and presence or absence of visual cues?

1.1.2.1.1.1.4.1.23
Will changes occur in long-term space flight in ability to detect movement of body member?

1.1.2.1.1.1.4.1.25
What is the course of change over time?

1.1.2.1.1.1.4.1.26
Are there significant differences between individuals in observed changes?

1.1.2.1.1.1.4.1.27
What physiological measurements are correlated with observed changes?

1.1.2.1.1.1.4.1.32
How is performance of this function affected by spacecraft dynamics (acceleration, rotation, vibration)?

1.1.2.1.1.1.4.1.33
How is performance of this function affected by absence of visual cues, speed of movement, rate of onset, and rate of change in velocity?

1.1.2.1.1.1.4.2.1
Will changes occur in long-duration space flight in ability to identify location of extremities?

1.1.2.1.1.1.4.2.3
What is the course of change over time?

1.1.2.1.1.1.4.2.4
Are there significant differences between individuals in observed changes?

1.1.2.1.1.1.4.2.5
What physiological measurements are correlated with observed changes?

1.1.2.1.1.1.4.2.9
How is performance of this function affected by spacecraft dynamics (acceleration, rotation, vibration)?

1.1.2.1.1.1.4.2.10
How is performance of this function affected by presence or absence of visual cues, using different extremities?

1.1.2.1.1.1.4.3.1
What is the effect of long-duration space flight in producing visual, auditory, and somesthetic illusions?

1.1.2.1.1.1.4.3.2
What is the course of change over time of any observed effects?

1.1.2.1.1.1.4.3.3
Are there significant individual differences?

EARTH ORBITAL EXPERIMENT PROGRAM
AND REQUIREMENTS STUDY

MANNED SPACEFLIGHT CAPABILITY

RESEARCH CLUSTER—1-BR-2
GROUP DYNAMICS AND PERSONAL ADJUSTMENT

C-1-119

RESEARCH CLUSTER SYNOPSIS--MANNED SPACEFLIGHT CAPABILITY
1-BR-2
Group Dynamics and Personal/Social Adjustment

1. Research Objectives

The ultimate objective of this research cluster is the determination of optimum crew structure, crew composition, training requirements, in-flight procedures, ground-to-space communication procedures, and spacecraft design criteria for sustaining and enhancing personal and group effectiveness. This objective will be realized through in-flight measurement and evaluation of verbal and physical crew interaction, crew productiveness, and individual crewman attitudes and moods as they are affected by the space environment, extended mission duration, crew size, characteristics of individual crew members, and variations in habitability design.

The research included in this research cluster is addressed to 28 critical issues categorized under the headings of Group Processes, Group Structure, Group Attitudes, Individual Personality Traits, Group Oriented Personality Traits, and Society-Oriented Personality Traits, which were derived from detailed analysis of the following long-range objectives to:

1. Determine man's individual behavior characteristics and group dynamics in space, identify individual characteristics and group dynamics in space, identify individual characteristics and group structures that are predictive of successful adaptation to the conditions of extended-duration space flight, and to develop methodology to evaluate crew interaction during missions.

2. Develop methods for crew selection.

3. Develop the technology for habitable living areas for space vehicles and on extraterrestrial surfaces.

4. Assure the functional integrity of man through the provision of appropriate protective and therapeutic measures.

Empirical data are needed from repeated observations in space of crews of different size and composition to determine the influence of long-duration space flight on the crew interaction processes; the structuring of group roles; and the development of and changes in individual attitudes and personality characteristics, particularly as they affect crew productivity, interpersonal conflict, and mission success.

2. Background and Current Status

As stated in the NASA Long-Range Plan for Aerospace Medicine, "...during extended missions, with more diverse activities in space, the characteristics of the individuals and the dynamic interactions of the various crew members can become more critical to the safety and successful accomplishment of the mission." Results of the research to be completed in this experiment group will be useful to NASA planners in (1) selection and training of flight crews (and of ground support crews), (2) the structuring of crews in terms of leadership and other responsibility roles, (3) the design of crew operating procedures and procedures for ground-to-space communications, (4) the provision of crew recreational and other stress-reducing activities and facilities, and (5) the design of habitable crew quarters.

From the beginning of the National Space Program, concern has been expressed by the scientific community about the potentially detrimental influence of space flight on group behavior. The eminently successful space flights to date, with highly selected and highly motivated small crews on short missions, have allayed these concerns for short missions, but the concern still exists for less motivated crews as mission lengths are extended. What is needed is a major coordinated effort in both ground-based and spaceflight research to provide the confidence needed before groups of men and their vehicles are committed to long-duration space ventures.

The present base of knowledge regarding group behavior under stress comes mainly from three sources. The anecdotal literature on shipwrecks and disasters, expeditions, remote duty stations, Navy ships and submarines, prisoner-of-war camps, and mental hospitals stresses the influence of isolation and confinement. The second source, the small-group research literature, is rich in theory and experimental technique. The third source of knowledge is that of research with confined crews, specifically aimed at simulating space conditions, which includes efforts by government agencies, universities, and industry. Additional contributions come from the research on extreme confinement and social deprivation, research on military groups such as bomber crews, and personnel psychology research with industrial groups. A number of reviews of this diversified literature have been published, some of which are noted in the references at the end of this synopsis.

Researchers in general agree that long-term isolation and confinement results in (1) time-phased stages of group behavior characterized by differences in work performance, emotional problems, and general activity; (2) degradation of perceptual, motor, and certain intellectual skills; (3) interpersonal conflict; (4) status leveling; (5) acceleration of interpersonal exchange; (6) monotony and boredom; and, (7) degraded social-emotional well-being.

From the standpoint of preventing or ameliorating the effects of long-term isolation and confinement, the literature suggests that crew compatibility is the single most important factor, but that effective leadership is a very important variable, along with patience, sensitivity, and the ability to give in to other crew members.

3. Description of Research

The specific research included in this cluster should be a continuing long-range effort on crews of different sizes, compositions, and under different mission conditions addressed to the collection of empirical, objective data through controlled observations of crew members during normal mission, experimental, and off-duty activities and opportunistically during or following periods of unusual high interpersonal stress. Normal observational sessions should be scheduled to sample the behavior response of concern approximately every 10 days during the mission cycle.

Crew productivity testing will require selecting a minimum of five different tasks, which are repeated periodically during the mission and preferably are of the type requiring more than one crew member for accomplishment. Parameters of interest are crew task time and error, which are best obtained unobtrusively by direct observation using TV cameras and video tape recordings incorporating a time reference.

Crew structure and process observational sessions (separate from productivity testing) should be scheduled for periods with maximum opportunities for crew interaction. Replications need not duplicate each other in terms of types of activities being performed nor crew members involved. Parameters of interest are verbal and physical interaction, and crew mood. Verbal and physical interaction data can be collected simultaneously with TV cameras and microphones, and recorded on videotape. With present state of the art, crew mood measurements will require the crew to respond to questionnaires.

Personal and social adjustment measurements will be made periodically by having the crewmen respond to standard or modified standard personality scales, such as FIRO-B, MMPI, Edwards Personal Preference Schedule, and other techniques for measuring personality and social adjustment. These measurements will be correlated with group process and structure results. It is hypothesized that personality variables will change from baseline values over extended durations in space.

Crew involvement in this research (except as experimental subjects, which imposes no additional crew time) is minimal and will include responding to questionnaires (135 minutes per crewman per 90-day cycle); initiation and termination of data taking; relocation and adjustment of microphone, cameras, and lights; and health checks of the data-gathering equipment.

One specific experiment within this research cluster was identified and described in detail under NASA Contract NAS1-9248, "Requirements Study for a Biotechnology Laboratory for Manned Orbiting Mission." It is designated in this study as 2-104, "Effects of

Space Flight on Crew Structure and Group Behavior," and is described briefly in Appendix H of this report.

4. Impact on Spacecraft

The impacts on the spacecraft for this research come primarily from measurement equipment and such expendables as magnetic tape. Four remotely controlled TV cameras with pan-tilt heads and zoom lens will be required. Total weight of these cameras is 24 lb and volume is 1.5 ft^3. Each requires 4 w of power while operating, and the total operating time for a 90-day cycle is estimated at 42 hr.

Assuming that crew productivity measurements will be taken at the rate of 30 frames per second and group process measurements at the rate of one frame every 3 seconds, ten rolls of 2400-foot magnetic tape will be required during each 90-day cycle.

Five (40Hz - 20 kHz) microphones, each weighing 0.5 lb, occupying 0.01 cu ft, and drawing 1 w of power are required. Operating time is approximately 40 hr.

A videotape recorder, monitor, switching circuit, and control panel will be housed in a console weighing 100 lb, having a volume of 5 cu ft, and requiring 100 w of power. Operating time is approximately 50 hr.

The primary time requirement on the crew is that required for responding to mood questionnaires, which will require approximately 135 minutes per crewman for each 90-day cycle. No special crew skills are required.

5. Required Supporting Technology Development

Before conducting the research identified in this research cluster, carefully controlled ground experiments are required for refinement of techniques for obtaining and analyzing video and audio records of group performance.

Although not necessary to the implementation of this research initially, the following developments are desirable to perform sophisticated research in space on group dynamics:

1. Development of techniques and instrumentation for unobtrusively obtaining subjective mood data from experimental subjects.

2. Development of techniques and instrumentation for automated extraction of group behavior data from video and audio records.

6. References

1. Earth Orbital Experiment Program and Requirements Study, Scientific and Technological Objectives. NASA Langley

Research Center, Hampton, Virginia, July 28, 1969. L13-9852.

2. S. B. Sells. A Model for the Social System for the Multiman Extended-Duration Spaceship. Aerospace Medicine, Vol. 37, No. 11, November 1966.

3. Bryce O. Hartman, et al. Human Factors Aspects of a 30-Day Extended Survivability Test of the Minuteman Missile. SAM-TDR-64-62, USAF School of Aviation Medicine, Brooks AFB, Texas, October 1964.

4. Irwin Altman and William W. Haythorn. Interpersonal Exchange in Isolation. Sociometry, Vol. 28, No. 4, December 1965, pp. 411-426.

5. Edward E. Eddowes. Survey of Leisure Time Activity; Implications for the Design of a Space Vehicle. Aerospace Medicine, 1961, pp. 541-544.

6. J. L. Wheaton. Fact and Fancy in Isolation and Sensory Deprivation. USAF School of Aviation Medicine, Randolph AFB, Texas, June 1958.

7. E. K. E. Gunderson. Biographical Predictors of Performance in an Environment. Journal of Psychology, Vol. 61, 1965, pp. 59-67.

8. Bryce Hartman and Donald E. Flinn. Crew Structure in Future Space Missions. Fifth Annual Lectures in Aerospace Medicine, USAF School of Aviation Medicine, Brooks AFB, Texas, 1964.

9. Douglas H. Hagen. Crew Interaction During a 30-Day Simulated Space Flight. Report 61-66, USAF School of Aviation Medicine, June 1961.

10. James R. Rawls, Charles N. McGaffey, Ronald E. Trego, and S. B. Sells. Some Determiners of Interpersonal Climate in Relation to Long-Durations Space Missions: A Review of Constructs and Research. Technical Report No. 5, Institute of Behavior Research, Texas Christian University, June 1968.

11. G. C. Homans. Social Behavior: Its Elementary Forms. New York, Harcourt, Brace, World, Inc., 1961.

12. Boris Mandrovsky. Special Report on One-Year Test of Life Support Systems (With Human Subjects Seated in Cabin). Prepublication draft, January 1969.

13. "60-Day Manned Test of a Regenerative Life Support System with Oxygen and Water Recovery, Part II." NASA CR-98500, Aerospace Medicine and Man-Machine Test Results, December 1968.

Critical Issues Addressed by Research Cluster 1-BR-2 GROUP DYNAMICS AND PERSONAL ADJUSTMENT

1.1.2.1.3.1
Will changes occur in long-duration space flight in patterning of group processes, structuring of group roles, or in group attitudes?

1.1.2.1.3.3
What is the course of change over time?

1.1.2.1.3.4
What are the relationships between observed changes and individual crew member personality characteristics?

1.1.2.1.3.5
Do groups of different composition show different responses to long-duration space flight?

1.1.2.1.3.6
How can changes be prevented or ameliorated?

1.1.2.1.3.8
What effects do observed changes have on crew performance, crew compatibility, morale, and motivation?

1.1.2.1.3.9
What is the effect of ground communications on group structure and dynamics?

1.1.2.1.3.10
How do changes in group structure and dynamics affect the effectiveness of leadership?

1.1.2.1.3.12
How do habitability design features affect group structure and dynamics?

1.1.2.1.3.13
How can participation in group activities in long-duration space flight be used to support group structure?

1.1.2.1.3.14
How is reduction of privacy related to group structure and process in long-duration space flight?

1.1.2.1.3.15
How can avenues of escape from interpersonal conflict be provided in long-duration space flight?

1.1.2.1.4.1
What is the relationship between specific personality traits and changes in indices of adjustment (morale, motivation, frustration, anxiety, hostility, ability to concentrate, fatigue, depression, and withdrawal) in long-duration space flight?

1.1.2.1.4.3
How can healthy social adjustment be facilitated during long-duration space flight?

1.1.2.1.4.5
Will changes in personality occur during long-duration space flight?

1.1.2.1.4.7
How do morale problems affect crew performance in long-duration space flight?

1.1.2.1.4.8
What is the effect of long-duration space flight on personal problem-solving abilities when the familiar modes for problem solving are not available?

1.1.2.1.4.12
How is social adjustment affected in long-duration space flight by the lack of contact with familiar (world news, family problems, significant persons and role partners, etc.)?

EARTH ORBITAL EXPERIMENT PROGRAM
AND REQUIREMENTS STUDY

MANNED SPACEFLIGHT CAPABILITY

RESEARCH CLUSTER—1-BR-3
COMPLEX TASK BEHAVIOR

C-1-127

RESEARCH CLUSTER SYNOPSIS--MANNED SPACEFLIGHT CAPABILITY
1-BR-3
Complex Task Behavior

1. Research Objectives

The research in this research cluster will investigate human capabilities in space in the performance of complex operator, maintenance, and scientific investigator mission tasks. The concentration is on real mission tasks of a complex nature rather than on measurements of elemental human behavioral characteristics such as vision, audition, or specific psychomotor capabilities. The specific measurements will be of tasks performed both inside and outside the spacecraft and in both zero gravity and various levels of artificial gravity.

Research included in this research cluster was derived by analysis in depth of NASA long-range objectives for manned spaceflight, particularly that objective which states "...to quantify human capabilities for performing physical and mental work as an operator and maintainer of space systems and equipment, and as a scientific investigator, and to provide data for decisions on the appropriate man-machine mix." By detailed analysis of the NASA objectives and their subobjectives, several hundred specific critical issues were identified. These in turn were summarized into 514 more general critical issues which formed the basis for the research to be included in this experiment group.

The long-range products of this research will include (1) a pool of data on man's unique task capabilities in space, (2) guidelines for making man/machine allocations of functions for extended space missions, (3) quantitative data for specifying the human transfer function for various task operations in space, and subsequently, mathematical modeling of human operations, (4) design characteristics of interfacing hardware for enhancement of human capabilities in space, and (5) a structure within which the man-machine dynamics of man in space can be evolved.

2. Background and Current Status

In expensive, complex systems, decisions regarding the use of man are among the most crucial to be made. Research and analysis addressed to this problem have been conducted for many years under the auspices of Government agencies, universities, and industrial firms. The basic problem in making man-versus-machine task allocations is eloquently described by Fogel (Reference 2): "The successful coupling of men to machines can only prove of benefit to mankind if it is viewed with vision and objectivity, making every use of the available knowledge about the behavior of men and their nonliving counterparts." To assign tasks to man, we must be completely aware of his capabilities and not be satisfied with vague generalizations about man's or machine's superiority in certain functions.

The literature on man's capabilities is rich in data on discrete capabilities (e.g., visual acuity, psychomotor reaction time, short term memory) (Reference 4), but much more limited with respect to complex behavior in which these discrete functions are combined into meaningful tasks. Significant efforts have been made to correct this deficiency, to quantify complex task behavior, and to transfer the results into engineering terms useful to system designers.

In the specific area of complex task behavior known as "tracking," considerable knowledge has been gained, not only on man's capability, but on design improvements such as display quickening to enhance that capability (References 6 and 7). Various agencies, including the Air Force under its maintenance data collection program and the American Institute for Research with its data store, have assembled banks of data on human performance (mostly task times) with emphasis on maintenance activities. In the quantification of human behavior considerable effort has been spent on developing mathematical approaches to the prediction of human error and the formulation of human reliability models (Reference 8). The engineering oriented research area of man-machine dynamics has looked upon man as a servo element in the system and attempted to quantify that function in terms of input/output, linear and nonlinear transfer functions, and the effects on system performance of such engineering refinements as control damping and display quickening (Reference 9).

Spaceflight to date has not produced any hard research data on human capabilities in space, but for the time durations and the space conditions experienced on both USA and Soviet flights, considerable advancement in knowledge has been achieved. On the basis of this knowledge it can be tentatively concluded that almost any task that man can perform on the ground can be performed in space provided proper and adequate restraints are used. This conclusion must be tempered with considerable caution when extravehicular tasks are included.

Measurement of human performance of complex tasks in space is required to determine (1) how man will perform under the conditions of extended spaceflight, (2) how his performance changes as a function of mission duration, and (3) differences in performance among crewmen of different backgrounds and training. This will require repeated, precise measurement of spaceflight tasks under operational conditions.

3. Description of Research

The research methodology in this research cluster is based on noninterference measurement of crew performance in on-going mission tasks in the areas of operations, maintenance, and scientific investigation. Measurement sessions will be scheduled to take advantage of opportunities as they arise for observation of the relevant tasks. Since it is desirable that a certain amount of research data on elemental behavior be collected before measurement of complex behavior is initiated, this experiment group will not commence at the first available opportunity (assumed to be 1974), but approximately 1 year later. In order to exhaust the opportunities for data collection in this area, it is assumed that the measurement program will extend for approximately 5 years.

The specific types of operator tasks are management and control, tracking, station keeping, and communicating. Maintenance tasks will include body translation and stabilization, mass translation and alignment, troubleshooting, tool use, adjusting, removing and replacing. Scientific investigator tasks encompass handling of data, making scientific observations, and making judgments such as to revise a specific experimental protocol.

System and mission analytic data will be used to select in advance the particular complex tasks which will be observed in orbit as part of this experiment group. Prelaunch simulation will be used to obtain reference data on the performance of those who will serve as experimental subjects in orbit. For each 90-day crew cycle, nine different tasks will be selected and observations of approximately 30 minutes each will be made three times (using the same experimental subject) during the 90-day cycle at approximately 15-day intervals. Thus a total of 27 measurement sessions are involved for each 90-day crew cycle. Each of these nine tasks will again be observed at the same repetition rate on the next two succeeding crew cycles to obtain data on a broader sample and to detect individual differences. Where possible, observations under both zero-g and artificial-g will be made in the same crew cycle. IVA tasks will be scheduled early in the program with EVA tasks following after experience has been gained in the measurement of the IVA tasks.

Parameters to be measured include task times, task errors, selected physiological indices (e.g., electrocardiogram, electrooculogram, metabolic cost), and subjective responses from crew regarding (1) hardware side of the man/machine interface and (2) difficulties encountered in performance of tasks.

Measurement techniques include use of onboard TV cameras, timers, biomedical instrumentation supplied under other experiment groups, and tape-recorded crew logs. It is anticipated that video recording will be performed on the first iteration of measurement for each task, and subsequently, onboard timers and direct observations will be used to acquire task time and error data.

Crew involvement will be minimal for this experiment group since experimental subjects will be performing their normal activities while being observed. A certain amount of time is required for initiation and monitoring of measurement equipment operation and for making entries in crew logs.

4. Impact on Spacecraft
Astronauts must serve as subjects in these experiments, but generally the intent is to measure performance on selected complex IVA and EVA tasks opportunistically as these tasks occur operationally during the mission. Thus crew member participation is on a noninterference basis; i.e., the gathering of data will not increase his workload. Initial recording of performance will be pictorial by means of videotape for later data reduction, either onboard, requiring crew time, or by an investigator on the ground. Performance data should be cross-validated via the gathering of repeat data on later missions. The participant will assume responsibility for starting and stopping the data gathering device and/or recording start and stop times and errors made during task accomplishment.

As a data-gathering device, the videotape camera and film should fit into a 2 ft by 1 ft by 1/2 ft box. Its playback monitor will be a 1 ft by 1 ft by 1/2 ft tape deck plus a 1 ft by 1-1/2 ft by 1-1/2 ft TV screen. The equipment will weigh approximately 150 lb and require 50 w of power during its operation.

5. Required Supporting Technology Development
The complex task research described here requires ongoing prelaunch analytic studies to obtain Operator, Maintenance, and Scientific Investigator task characteristics in detail and predictions of task performance in orbit. Reference data will be gathered on mission-assigned astronauts prior to launch.

6. References

1. Earth Orbital Experiment Program and Requirements Study Scientific and Technological Objectives, L13-9852. NASA Langley Research Center, Hampton, Virginia, July 28, 1969.

2. L. J. Fogel. Biotechnology: Concepts and Applications. Chapter 18, Man-Machine Task Allocation and System Design. Prentice-Hall, Inc., Englewood Cliffs, N.J., 1963.

3. P. Webb (editor). Bioastronautics Data Book, Section 18, The Human Operator. NASA-SP-3006, Scientific and Technical Information Division, National Aeronautics and Space Administration, 1964.

4. C. T. Morgan, A. Chapanis, J. S. Cook, III, and M. W. Lund (editors). Human Engineering Guide to Equipment Design, Chapter 1, The Man Machine System McGraw-Hill Book Co., Inc., New York, 1963.

5. G. L. Murphy. The Role of Man in Earth Observations (prepared for the Earth Surveys Steering Group, NASA). McDonnell-Douglas Astronautics Company, Huntington Beach, California, October 1, 1969.

6. F. V. Taylor and H. P. Birmingham. Simplifying the Pilot's Task Through Display Quickening. Journal of Aviation Medicine, Vol. 27, No. 1 (1956), pages 27-31.

7. John W. Senders. Human Tracking Behavior, M-H Aero Document U-ED 6141. Minneapolis-Honeywell Regulator Corp., Minneapolis, Minnesota, November 1959.

8. E. W. Pickrel. Quantification of Human Performance in Large Complex Systems. Human Factors Journal. December 1964.

9. D. T. McRuer and E. Krendel. The Human as a Component in a Servo System. Journal of the Franklin Institute, 1959.

Critical Issues Addressed by Research Cluster
1-BR-3
COMPLEX TASK BEHAVIOR

1.1.2.1.2.1
Will changes occur in long-duration spaceflight in operator, maintenance, or scientific investigation capabilities?

1.1.2.1.2.2
What is the course of change over time of any observed changes?

1.1.2.1.2.3
Are there significant differences between individuals in observed changes?

1.1.2.1.2.7
How is human performance of operator, maintenance, and scientific investigation tasks affected by spacecraft dynamics?.

1.1.2.1.2.13
How is time stress related to performance of operator, maintenance, and scientific investigation tasks?

EARTH ORBITAL EXPERIMENT PROGRAM AND REQUIREMENTS STUDY

MANNED SPACEFLIGHT CAPABILITY

RESEARCH CLUSTER–1-BR-4
SKILL RETENTION

C-1-133

RESEARCH CLUSTER SYNOPSIS--MANNED SPACEFLIGHT CAPABILITY
1-BR-4
Skill Retention

1. Research Objectives

This research cluster is concerned with investigating the acquisition and retention of critical skills needed in extended spaceflight. The purpose of this research is to identify those skills which degrade in space and the time course of their degradation, to discover ways of preventing such degradation, and to evaluate procedures and equipment for maintaining critical skills in space.

The critical issues to which this research cluster seeks answers were derived by detailed analysis of the following NASA long-range objectives to:

1. . Obtain behavioral data on men over extended periods of time--from six months to one year in duration--and at various levels of artificial gravity.

2. Identify requirements and develop equipment and procedures to assure the effectiveness of man in the pursuit of science experiments, applications tasks, and vehicle operations.

3. Develop methods for crew selection, proficiency assessment, maintenance of skills, and identification of training requirements.

There is need for a long-term program of coordinated ground-based and in-space research which first identifies and describes the degradation of specific space-required skills and then evaluates various solutions, such as overtraining before launch, warmup and rehearsal during flight, and retention aids such as checklists and task simplification techniques.

2. Background and Current Status

Man makes his impact on the systems with which he interfaces by the performance of tasks. He must be trained to perform these tasks, and to retain proficiency he must perform the tasks repeatedly and periodically, either in the real situation or in a practice situation. An extensive literature has developed both in this country and abroad describing in detail the many tasks which man may perform in terms of task times, skill requirements, learning times, etc. (References 1, 2, 3, and 13.) The training research literature contains a great deal of data on skills which degrade most rapidly, requirements for periodic retraining, and the usefulness of task simplification and retention aid techniques in preventing degradation (References 4, 5, 6, 7, and 8). Ground-based simulation studies have (1) contributed to identification of skills which may potentially degrade over time in space, and (2) proposed techniques for overcoming the problem (References 9, 10, 11, and 12).

Brief spaceflight experiences have shown losses of body fluids, muscles, and bone, which may interfere with accomplishment of some tasks, especially if man tries to continue his long-practiced Earth habits after conditions have changed. Analytic studies have identified space-type complex operations that must be performed under such stringent time requirements and so infrequently that skill retention may be a problem. Simulation studies have shown that terrain-tracking tasks, such as mapping an area or coming in for a landing, can show serious performance degradation in 200 days. The mapping of areas exemplifies a mission-specific activity. The landing task will be a part of all space missions, and being in shape to withstand the forces of reentry is only one of the requirements for task accomplishment.

Both Soviet and American spacecrews have accomplished reentry tasks manually after automatic system failure, a fact which illustrates the critical relation of skills retention research to man's ability to perform as an operator and maintainer of spacecraft systems and equipment.

For extended spaceflight there is a considerable gap in extant knowledge regarding (1) maintenance of proficiency for extended durations under space conditions, (2) the specific characteristics of any degradation which might occur, (3) the frequency with which retraining should occur, and (4) the form (rehearsal, warmup, etc.) which such retraining should take.

3. Description of Research

This research cluster requires in-orbit observation of crew performance on a variety of tasks, selected to represent those skills which ground research and analysis have indicated may degrade over extended time in space. Two types of skill degradation will be investigated--that which occurs because of long-term disuse of the skill and that which occurs gradually and almost imperceptibly in skills which are used frequently. The repertoire of tasks selected for observation will therefore include both infrequently and frequently used tasks, and the observations will in some cases be separated by long intervals and in other cases will occur quite frequently. The first phases of this research will concentrate on identification of those skills which degrade and the nature and time course of their degradation, while later phases (beginning in the second year) will investigate techniques, equipment, and procedures for preventing degradation.

Usually, tasks selected for observation will be operational tasks, and a mix will be selected which includes those which are performed infrequently and those which occur frequently. Tasks of the following types are candidates: tracking, control of vehicle for image motion compensation, identification of space and Earth targets, monitoring of displays for infrequently appearing signals, maintenance tasks requiring unique psychomotor capabilities, photointerpretation, rendezvous and docking, and direct observation of phenomena which require long-term recall of scientific principles or knowledge. In addition, some tasks which cannot be performed operationally during the on-orbit mission phase will be simulated onboard (e.g., reentry, landing), and in these cases, simulation equipment such as a flight centrifuge, displays, and controls will be provided.

For planning purposes it is assumed that for any given crew cycle, five crew tasks will be investigated, with a mix as follows: two operational tasks which are performed frequently -- measurements will be made approximately every three days; two operational tasks which are performed infrequently (at least 30-day intervals)-- measured as they occur; and--one simulated task which will be simulated and observed for three different crewman--one at 30, one at 60, and one at 90 days after mission start. Ninety-day intervals are shown as the maximum, but if crew cycle extends longer than 90 days, measurements should be extended to the maximum interval. Each measurement period will consume a maximum of 30 minutes. For those tasks which take longer than 30 minutes, only the most significant 30-minute portion of the task will be measured. As each task is performed for measurement purposes, it will be observed by TV cameras and video-tape-recorded for storage and logistics vehicle return or it will be transmitted to Earth for analysis. The desired number of repeat recordings of performance on any given task will be determined via statistical sampling techniques; then subsequent repetitions of the same task will not be video-recorded.

The major parameters to be measured are task time and error. Task time will be in seconds and can be measured and recorded by the onboard timing system or can be extracted from the video record. Errors can be extracted from the video-tape, but will also be available from automatically recorded indicators of errors in pitch, roll, yaw, propellant usage, and control actions; and also from subject reports and direct observations by other crewmen.

One experiment within this research cluster was identified and described in detail under NASA contract NAS1-9248, "Requirements Study for a Biotechnology Laboratory for Manned Earth Orbiting Missions." It was designated in that study as "2-107 Skill Retention in Extended Spaceflight," and is described briefly in Appendix H of this report.

4. Impact on Spacecraft

Astronauts must serve as subjects in the orbital training experiments. Many measurements may be obtained by self-test techniques and require only the time of the experiment subjects.

Experiments requiring both subject and observer will be grouped into the same sessions.

Supporting equipment requirements vary greatly, but a "worst case" example of high-demand on the spacecraft is provided by the centrifuge: 1, 720 pounds, 2, 000 cubic feet, and 5, 300 watts peak power.

5. Required Supporting Technology Development

Most of the skills-retention research discussed here requires ongoing analytic studies to delineate more precisely the operational problems and skills-retention hypotheses to be tested. Potential training equipment and retention aids must be identified and developed in simulation facilities on Earth. Benchmark data must be gathered on the mission-assigned astronauts prior to launch. Then the equipment, aids, and techniques may be tested in orbit. This research cluster program involves many different experiments and extends over a considerable span of time, and a variety of missions and systems.

6. References

1. P. M. Fitts and M. I. Posner. Human Performance. Wadsworth Publishing Company, 1967.

2. D. Payne and J. W. Altman. An Index of Electronic Equipment Operability: Report of Development. AIR-C-43-1/62-FR, American Institute for Research, Pittsburgh, Pennsylvania.

3. D. Payne, J. W. Altman, and R. W. Smith. An Index of Electronic Equipment Operability: Instruction Manual: AIR-C-43-1/62, American Institute for Research, Pittsburgh, Pennsylvania.

4. E. A. Biladeau. Acquisition of Skills. Academic Press, New York, 1966.

5. A. W. Melton. Categories of Learning. Academic Press, New York, 1966.

6. E. A. Fleishman and J. F. Parker. Factors in the Retention and Relearning of Perceptual-Motor Skills. Journal of Experimental Psychology, 64, 1962.

7. J. C. Naylor and G. E. Briggs. Long Term Retention of Learned Skills: A Review of the Literature, ASD TR 61-390, Wright-Patterson Air Force Base, Ohio, August, 1961.

8. J. C. Naylor, G. E. Briggs, and W. G. Reed. The Effects of Task Organization, Training Time, and Retention Interval on the Retention of Skill. AMRL TDR 82-107, Wright-Patterson AFB, Ohio, September, 1962.

9. W. E. Lewis and E. W. Youngling. Manual Optical Viewing from Space: A Review. Report MDC E0007, McDonnell Douglas Astronautics Company--East, 1969.

10. E. W. Youngling, E. M. Sharpe, D. S. Ricketson, and D. W. McGee. Crew Skill Retention for Space Missions up to 200 days. Report F766, McDonnell Douglas Astronautics Company, St. Louis, Missouri, December, 1968.

11. Training Aspects of Orbital Reconnaissance Tasks. Report G610, McDonnell Douglas Astronautics Company, St. Louis, Missouri.

12. M. Grodsky, D. Roberts, and J. Mandow. Test Pilot Retention of Simulated Lunar Mission Skills. Report ER 14139, Martin Company, Baltimore, Maryland, March, 1966.

13. R. B. Miller. Task Description and Analysis. In R. M. Gagne, Psychological Principles in System Development, Holt, Rinehart and Winston, New York, 1962.

14. Earth Orbital Experiment Program and Requirements Study Scientific and Technological Objectives. L13-9852, NASA Langley Research Center, Hampton, Virginia, July 28, 1969.

Critical Issues Addressed by Research Cluster

1-BR-4

SKILL RETENTION

1.1.2.1.5.2
How effective is preflight training on mission success in terms of crew performance, physical fitness, social adjustment, individual behavior, and retention of skills.

1.1.2.1.5.3
How effective is in-flight training or practice in maintaining seldom-used skills?

1.1.2.1.5.4
How do specific skills degrade over time in space?

EARTH ORBITAL EXPERIMENT PROGRAM
AND REQUIREMENTS STUDY

MANNED SPACEFLIGHT CAPABILITY

RESEARCH CLUSTER—1-BR-6
PERFORMANCE MEASUREMENT

C-1-139

RESEARCH CLUSTER SYNOPSIS--MANNED SPACEFLIGHT CAPABILITY
1-BR-6
Performance Measurement

1. Research Objectives

Performance measurement, as used in this research cluster, includes all activities, techniques, and equipment required in space to monitor, measure, and assess crew performance of tasks, psychological states of individual crew members, crew interaction and group processes, and personality variables. The research in this experiment group is not separate and distinct, but forms a part of all experiments involving human behavior. Since this experiment group imposes no additional measurement requirements, equipment, or crew tasks beyond those described for other experiment groups, a detailed experiment group description has not been prepared.

The objective of this research cluster is to evaluate various methods of assessing human performance in space. In arriving at the specific critical issues to which this research should be addressed, a detailed analysis was made of the relevant long-range NASA objectives, particularly those that state: ". . . to develop advanced instrumentation for measurement of body systems, and develop methods for crew proficiency assessment." It is assumed that advanced measurement methods will be developed and thoroughly tested in ground simulations and that measurements using these advanced techniques will then be made in orbit. The research described herein consists of accumulating data from numerous in-orbit experiments to validate the equipment and techniques in actual use.

The Performance Measurement research cluster is seen as a discrete integrated cluster (coordinated with on-going ground-based programs) addressed to the evaluation of techniques and equipment for measuring:

1. Performance of complex tasks.
2. Changes in individual behavioral characteristics.
3. Subjective moods and attitudes.
4. Alertness and fatigue.
5. Subjective reactions to conditions.

2. Background and Current Status

Traditionally, human performance in Earth-based programs has been measured by means of time and motion study, direct measurement of task results, correlation of performance on artificial tasks with real tasks, and paper-and-pencil tests. For the most part, these techniques have served their purposes well and most of what we know about human performance is based on these measurement methods. There are, however, problems in directly applying such techniques to the measurement of human performance and psychological state in space. These problems involve space vehicle constraints on power, communications bandwidth, and crew time; and the nature of the behavioral processes of primary concern, which respond to stresses slowly with time (Reference 1, page 162). The 1968 Winter Study on Uses of manned Space Flight in the 1975-1985 period identified one of the major problems facing man/systems integration as being the determination of the optimal measurement techniques required to assess performance (Reference 2, page 122).

Considerable ground-based research has been performed on advanced methods for assessing human performance. These methods can be classified as direct, indirect, or subjective. A major continuing problem in the evaluation of any measurement method is the criterion problem. What is needed is an independent, uncontaminated criterion of human performance under operational conditions to check the validity of techniques that in the past have been accepted primarily on the basis of analysis or opinion.

Direct measurement relies on techniques of directly observing the behavior being assessed. Time and motion studies, use of motion picture or TV cameras, instrumentation of the equipment on which the task is being performed, and direct observation and recording by a human observer are examples of direct measurement. The use of motion pictures and TV cameras will be evaluated in early Skylab flights, and time and motion approaches using these same techniques are an integral part of a planned integrated medical and behavioral laboratory measurement system. TV camera techniques have been used in ground simulation experiments, including Tektite, Gulfstream, and the McDonnell - Douglas Space Cabin Simulator tests. In an earlier McDonnell-Douglas simulation, the activity of crew members was measured by means of photoelectric cells (Reference 3). The major problem with the use of motion-picture film or video tape is in the process of analysis (obtaining relevant information from the picture). An interesting approach to automating the retrieval of data from this type of record is presented by Thomas (Reference 4), who recorded the activity of animals in cages on motion picture film, and automatically retrieved it by using a photoelectric cell to scan the film, converting it to audio information, and recording it on magnetic tape.

Indirect techniques include using physiological parameters as indirect measures of performance or state, synthetic task batteries, and inferences of performance proficiency or behavioral state from indirect indicators, such as voice or activity patterns. Muscle-action potential (as measured by electromyographic techniques), brain potential (electroencephalograph), eye movements, catecholamines, average evoked response (potentials at the cortex evoked by external stimuli), galvanic skin response, and blood pressure have been investigated and offer promise as indicators of such physical conditions as alertness, vigilance, levels of subjective stress, and fatigue (References 5 and 6). Significant research has been completed on the use of speech as an indicator of psychological stress and emotional state, principally at Bell Laboratories but also in experiments conducted by government agencies (References 7 and 8).

Subjective methods are based on the premise that the individual himself knows how well he is doing and can reliably report his proficiency, reaction to conditions, and psychological state. These methods include responses to questionnaires, unstructured entries in crew logs, critical incident techniques, and self-scoring. In the space program to date this kind of technique has been the main source of data on human performance, and present developmental efforts are addressed primarily to making the reporting more efficient by decreasing crew time and streamlining the handling of the resultant data.

In a long-term on-orbit manned space station, data will be collected in sufficient quantity and by sufficiently diverse means to permit evaluation of the various direct, indirect, and subjective techniques. What is needed is a coordinated program of ground-based development and test coupled with in-flight data collection, which permits long-term evaluation of the various methods against criteria of reliability, validity, economy, and crew acceptability.

3. Description of Research

The research in this research cluster will require close coordination between the person or agency assigned responsibility for its implementation and the principal investigator in every experimental area that involves assessment of crew performance. A carefully prepared plan of data segregation and accumulation will be worked out well in advance of flight for selected aspects of performance. The selected areas of performance will be those on which good criterion data are available and on which data relevant to several measurement techniques (e. g., TV cameras, physiological indicators, and subjective reports) will be obtained. Analysis of the data and evaluation of specific measurement techniques will be performed postflight on the ground.

To realize the maximum value, it may be necessary for some other experiments to modify their data-taking to permit simultaneous use of several techniques. In many cases, however, this will be done as part of the natural course of conducting the experiment.

Crew participation in this research cluster is negligible since the onboard data will be telemetered or otherwise sent to the ground for analysis.

4. Impact on Spacecraft

This experiment group has no appreciable effect on spacecraft subsystems, data handling, or flight crew time.

5. Required Supporting Technology Development

No additional requirements are imposed beyond the requirements for developing measurement technology identified in other experiment groups.

6. References

1. Space Research, Directions for the Future. Report of a Study by the Space Sciences Board, National Academy of Sciences--National Research Council, Washington, D. C., February 1966.

2. Proceedings of the Winter Study on Uses of Manned Space Flight, 1975 to 1985, Vol. II. A conference held in La Jolla, California, December 6-9, 1968, NASA, Washington, D. C., 1969.

3. M. Goodman and W. C. Middleton, Crew Locomotion Disturbances in a Space Cabin Simulator, Journal of Spacecraft and Rockets, Vol. 6, No. 10, October 1969, pp. 1207-09.

4. Anthony A. Thomas, Quantitative Analysis of Spontaneous Activity: Effects of Long-Term Continuous Exposure to Space Cabin Atmospheres. Proceedings of the Third Annual Conference on Atmospheric Contamination in Confined Spaces, AMRL-AMD-AFSC, Report AMRL-TR-67-200, Wright Patterson AFB, Ohio, Report December 1967, pp. 311-20.

5. J. A. Freeman. Monitoring Psychomotor Response to Stress by Evoked Auditory Responses. Report SAM-TR-65-42, USAF School of Aviation Medicine, Brooks AFB, Texas, 1965.

6. P. M. Fitts, R. E. Jones, and J. L. Milton. Eye Fixation of Aircraft Pilots. USAF AMC TR 5839, October 1949.

7. A. Chapanis, W. R. Garner, and C. T. Morgan, Applied Experimental Psychology. (Chapter 8, Speech.) John Wiley and Sons, Inc., New York, 1961.

8. Carl E. Williams and Kenneth N. Stevens, On Determining the Emotional State of Pilots During Flight. Aerospace Medicine, December 1969, pp. 1369-1372.

9. Earth Orbital Experiment Program and Requirements Study, Scientific and Technological Objectives. L13-9852, NASA, Langley Research Center, Hampton, Virginia, July 28, 1969.

Critical Issues Addressed By Research Cluster 1-BR-6 PERFORMANCE MEASUREMENT

1.1.2.1.6.1
How sensitive are sampling techniques in identifying differences in performance in long-duration space missions?

1.1.2.1.6.2
Can measures of task components (e.g., abilities) be used to validly infer performance on the total task?

1.1.2.1.6.5
How reliable and valid are various direct, indirect, and subjective methods of monitoring and assessing crew performance in long-duration spaceflight?

1.1.2.1.6.6
What are the spacecraft support requirements for the various methods of monitoring and assessing performance in long-duration spaceflight?

1.1.2.1.6.7
How does use of the various methods of monitoring and assessing performance in long-duration spaceflight influence or change the behavior they are attempting to measure?

TABLE 1. LEGEND OF CODES USED IN CREW ACTIVITY MATRICES

Table 1 is an explanation of the codes used in the following matrices. The matrices summarize the inflight crew tasks required to conduct and support the research identified in the synopses.

TYPE OF ACTIVITY

0 - Not covered below

1 - Experimental subject

2 Spacecraft operations

3 - Preexperiment equipment preparation

4 - Maintenance of equipment

5 - Conduct of experiment

6 - Evaluate intermediate results

7 - Direct observation of phenomena

8 - Data handling

9 - Communications; initiate and receive transmissions (telemetry, voice)

CREW SKILL

0 - No special skill required

1 - Medicine

2 - Biology

3 - Physiology

4 - Psychology

5 - Engineering

6 - Astronomy

7 - Physics

8 - Oceanography

9 - Forestry

10 - Agriculture

11 - Geology

12 - Meteorology

13 - Geography

14 - Cartography

15 - Hydrology

16 - Navigation

17 - Communications

18 - Radiology

19 - Instrumentation

20 - Photography

21 - Astronaut

22 - Other

Each code includes the first one or two digits describing the discipline and a second code letter describing level of skill: A for highest skill level (requires professional training with degree or advanced degree in discipline such as M. D.): B for semiprofessional, the traditional technician level requiring several years of training; C for technician level which requires some special training.

CREW ACTIVITY MATRIX

RESEARCH CLUSTER NO.	TASK DESCRIPTION	EXPERIMENT EQUIPMENT	TYPE OF ACTIVITY	PECULIAR ENVIRONMENTAL REQUIREMENTS	EXCLUSIVE	CREW SKILL	FREQUENCY	TASK TIME (MIN)	NO. OF CREWMEN	START	DURATION	TASK CONCURRENCY
1-BR-1-1	Vision											
	Set up/prepare equipment for testing vision	Vision Test Apparatus (IMBLMS)	3	Repeat for partial "g" conditions of a rotating space station		O-C	1/20 days	3	1	74	4	
	Turn on data recording devices	Console & computer	8			O-C	1/20 days	1	1	74	4	
	Turn on Vision Test Apparatus		5			O-C	1/20 days	1	1	74	4	
	Observe projected visual stimuli and report perceptions by actuating appropriate recording controls.		1		X	O-C	"	120	6	74	4	
	Turn off Vision Test Apparatus		5			O-C	"	1	1	74	4	
	Turn off data recording devices		8			O-C	"	1	1	74	4	
	Return equipment to standby/stored status		5			O-C	"	3	1	74	4	

RESEARCH CLUSTER NO. 1-BR-1-2

CREW ACTIVITY MATRIX

RESEARCH CLUSTER NO.	TASK DESCRIPTION	EXPERIMENT EQUIPMENT	TYPE OF ACTIVITY	PECULIAR ENVIRONMENTAL REQUIREMENTS	EXCLUSIVE	CREW SKILL	FREQUENCY	TASK TIME (MIN)	NO. OF CREWMEN	START	DURATION	TASK CONCURRENCY
1-BR-1-2	Behavior Effects of Acoustic Environment											
	Set up/prepare equipment for testing hearing	Auditory Test Apparatus	3	Repeat for partial "g" conditions of a rotating space stat		O-C	"	3	1	74	4	
	Turn on data recording devices	Console & computer	8			O-C	"	1	1	74	4	
	Turn on Auditory Test Apparatus	(IMBLMS)	5			O-C	"	1	1	74	1	
	Observe projected auditory stimuli and report perceptions by actuating appropriate recording controls.		1		X	O-C	"	75	6	74	1	
	Turn off Auditory Test Apparatus		5			O-C	"	1	1	74	1	
	Turn off data recording devices		8			O-C	"	1	1	74	1	
	Return equipment to standby/stored status		5			O-C	"	3	1	74	1	

CREW ACTIVITY MATRIX

RESEARCH CLUSTER NO. 1-BR-1-3

RESEARCH CLUSTER NO.	TASK DESCRIPTION	EXPERIMENT EQUIPMENT	TYPE OF ACTIVITY	PECULIAR ENVIRONMENTAL REQUIREMENTS	EXCLUSIVE	CREW SKILL	FREQUENCY	TASK TIME (MIN)	NO. OF CREWMEN	START	DURATION	TASK CONCURRENCY
1-BR-1-3	Psychomotor											
	Set up/prepare equipment for psychomotor testing	Psychomotor	3	Repeat for the		O-C	"	3	1	74	4	
	Turn on data recording devices	Test Apparatus Console and	8	partial "g" conditions of a rotat-		O-C	"	1	1	74	4	
	Turn on Psychomotor Test Apparatus	Computer (IMBLMS)	5	ing space station.		O-C	"	1	1	74	4	
	Observe stimuli and respond by appropriate actuation of response controls (data record is linked to controls).		1		X	O-C	"	120	6	74	4	
	Turn off Psychomotor Test Apparatus		5			O-C	"	1	1	74	4	
	Turn off data recording devices		8			O-C	"	1	1	74	4	
	Return equipment to standby/stored status		5			O-C	"	3	1	74	4	
	Psychomotor											
	Set up/prepare equipment for psychomotor testing	Psychomotor Test Apparatus	3	Repeat for the par-		O-C	1/20 day	3	1	74	4	
	Turn on data recording devices	Console and	8	tial "g" conditions of a rotating		O-C	"	1	1	74	4	
	Turn on Psychomotor Test Apparatus	Computer	5	space station		O-C	"	1	1	74	4	
	Observe stimuli and respond by appropriate actuation of response controls (data record is linked to controls)	(IMBLMS)	1		X	O-C	"	120	6	74	4	
	Turn off Psychomotor Test Apparatus		5			O-C	"	1	1	74	4	
	Turn off data recording devices		8			O-C	"	1	1	74	4	
	Return equipment to standby/stored status		5			O-C	"	3	1	74	4	

RESEARCH CLUSTER NO. 1-BR-1-4

CREW ACTIVITY MATRIX

RESEARCH CLUSTER NO.	TASK DESCRIPTION	EXPERIMENT EQUIPMENT	TYPE OF ACTIVITY	PECULIAR ENVIRONMENTAL REQUIREMENTS	EXCLUSIVE	CREW SKILL	FREQUENCY	TASK TIME (MIN)	NO. OF CREWMEN	START	DURATION	TASK CONTINGENCY
1-BR-1-4	Cognitive											
	Set up/prepare equipment for cognitive testing	Cognitive Test Apparatus Console and Computer (IMBIMS)	3	Repeat for the partial "g" conditions of a rotating space station.		O-C	1/2) days	3	1	74	1	
	Turn on data recording devices		8			O-C	"	1	1	74	1	
	Turn on Cognitive Test Apparatus		5			O-C	"	1	1	74	1	
	Observe stimuli and input responses to the recording device by actuating response controls.		1		X	O-C	"	120	6	74	1	
	Turn off Cognitive Test Apparatus		5			O-C	"	1	1	74	1	
	Turn off data recording devices		8			O-C	"	1	1	74	1	
	Return equipment to standby/stored status		5			O-C	"	3	1	74	1	

CREW ACTIVITY MATRIX

RESEARCH CLUSTER NO.	TASK DESCRIPTION	EXPERIMENT EQUIPMENT	TYPE OF ACTIVITY	PECULIAR ENVIRONMENTAL REQUIREMENTS	EXCLUSIVE	CREW SKILL	FREQUENCY	TASK TIME (MIN)	NO. OF CREWMEN	START	DURATION	TASK CONCURRENCY
1-BR-1-5	Orientation											
	Set up/prepare equipment for Testing Orientation	Orientation	3	Repeat for partial		O-C	3/90 days	10	1	74	1	
	Put on physiological monitoring sensors	Test Apparatus (IMBLMS)	5	"g" conditions of		O-C	"	5	6	74	1	
	Turn on data recording devices	EKG, EOG	8	rotating space station.		O-C	"	1	1	74	1	
	Turn on testing apparatus	blendfold	5			O-C	"	1	1	74	1	
	Observe stimuli and respond by appropriate actuation of response controls (data record is linked to controls)	earplugs	1		X	O-C	"	80	6	74	1	
	Monitor experiment subject and apparatus		5		X	1-A	"	80	6	74	1	
	Turn off Orientation Test apparatus		5			O-C	"	1	1	74	1	
	Turn off data recording devices		8			O-C	3/90 days	1	1	74	1	
	Take off physiological monitoring sensors		5			O-C	"	3	6	74	1	
	Return equipment to standby/stored status		5			O-C	"	5	1	74	1	
	Make entries in Crew Logs	Tape Recorder	8			O-C	1/15 days	5	1	74	1	

RESEARCH CLUSTER NO. 1-BR-2

CREW ACTIVITY MATRIX

RESEARCH CLUSTER NO.	TASK DESCRIPTION	EXPERIMENT EQUIPMENT	TYPE OF ACTIVITY	PECULIAR ENVIRONMENTAL REQUIREMENTS	EXCLUSIVE	CREW SKILL	FREQUENCY	TASK TIME (MIN)	NO. OF CREWMEN	START	DURATION	TASK CONCURRENCY
1-BR-2	Group Dynamics and Personal & Social Adjustment											
1-BR-2-1	Group Dynamics											
	Set up/prepare microphones, cameras, lights for gathering observations.	TV cameras, monitors,	3			O-C	1/10 days	5	1	74	3	
	Prepare the film, telemetry, computer for recording/ storing data.	portable micro-phones and recorders.	8			O-C	"	5	1	74	3	
	Turn on the data gathering devices		8				"	1	1	74	3	
	Monitor the data gathering devices which are recording Group Dynamics data during the accomplishment of selected tasks.		5			O-C	"	0	6	74	3	
	Turn off the data gathering devices		8			O-C	"	1	1	74	3	
	Accomplish maintenance on the cameras, lights, data gathering devices so they are ready for next usage.		4			O-C	"	5	1	74	3	
	Return equipment to standby/stored status		5			O-C	"	5	1	74	3	
	Respond to questionnaires		1			O-C	Sum per	90 days 135	6	74	3	

CREW ACTIVITY MATRIX

RESEARCH CLUSTER NO.	TASK DESCRIPTION	EXPERIMENT EQUIPMENT	TYPE OF ACTIVITY	PECULIAR ENVIRONMENTAL REQUIREMENTS	EXCLUSIVE	CREW SKILL	FREQUENCY	TASK TIME (MIN)	NO. OF CREWMEN	START	DURATION	TASK CONCURRENCY
1-BR-3	Complex Task Behavior	Both IVA and EVA										
	Put on the physiological monitoring devices.	EKG, EOG, etc.	5	Repeat for partial "g" conditions of a rotating space station.		O-C	27/90 Days	3	2	75	6	
	Switch on the physiological monitoring devices.	switches	5			O-C	"	1	2	75	6	
	Switch on the data recording devices.	switches	8			O-C	"	1	2	75	6	
	Monitor the camera which is recording crew performance data during accomplishment of selected tasks.	Film versus Video Tape.	1.5			O-C	"	0	1	75	6	
	Switch off the data recording devices.	switches	8			O-C	"	1	2	75	6	
	Switch off the physiological monitoring devices.	EKG, EOG, etc.	5			O-C	"	1	2	75	6	
	Take off the physiological monitoring devices.		5			O-C	"	3	2	75	6	
	Make entries in crew logs	Tape recorder	8			O-C	"	3	2	75	6	

CREW ACTIVITY MATRIX

RESEARCH CLUSTER NO. 1-BR-4

RESEARCH CLUSTER NO.	TASK DESCRIPTION	EXPERIMENT EQUIPMENT	TYPE OF ACTIVITY	PECULIAR ENVIRONMENTAL REQUIREMENTS	EXCLUSIVE	CREW SKILL	FREQUENCY	TASK TIME (MIN)	NO. OF CREWMEN	START	DURATION	TASK CONCURRENCE
1-BR-4	**Skills Retention**											
	Set up/prepare equipment for training experiment (frequently occurring tasks).		3			21-C	Ea 3 days	5	2	74	6	
	Turn on data recording devices		8			0-C	Ea 3 days	1	2	74	6	
	Accomplish training (operational task)		1,2,5		X	21-A	Ea 3 days	0	2	74	6	
	Turn off data recording devices.		8			0-C	Ea 3 days	1	2	74	6	
	Return equipment to appropriate status		4			21-C	Ea 3 days	5	2	74	6	
	Set up/prepare equipment for training experiment (infrequently occurring tasks).		3			16-C	Monthly	5	2	74	6	
	Turn on data recording devices.		8			0-C	Monthly	1	2	74	6	
	Accomplish training (operational task)		1,2,5		X	16-A	Monthly	0	2	74	6	
	Turn off data recording devices.		8			0-C	Monthly	1	2	74	6	
	Return equipment to appropriate status		4			16-C	Montlly	5	2	74	6	
	Set up/prepare equipment for training experiment (simulation activity).		3			5-C	Monthly	5	1	74	6	
	Put on physiological monitoring devices		5			0-C	Monthly	3	1	74	6	
	Turn on data recording devices.		8			0-C	Monthly	1	1	74	6	
	Accomplish simulation activity		1,2,5		X	5-B	Monthly	30	1	74	6	
	Monitor subject and equipment.		5		X	1-A	Monthly	30	1	74	6	
	Turn off data recording devices.					0-C	Monthly	1	1	74	6	
	Take off physiological monitoring devices.		5			0-C	Monthly	3	1	74	6	
	Return equipment to appropriate status.					5-C	Monthly	5	1	74	6	

EARTH ORBITAL EXPERIMENT PROGRAM AND REQUIREMENTS STUDY

MANNED SPACEFLIGHT CAPABILITY

RESEARCH CLUSTER–1-MM-1 CONTROLS AND DISPLAYS

C-1-153

RESEARCH CLUSTER SYNOPSIS—MANNED SPACEFLIGHT CAPABILITY
1-MM-1
Controls and Displays

1. Research Objectives

The primary objective of this research cluster is to accumulate in-space human engineering data on the interfaces between man and controls and displays, under conditions of extended duration, weightlessness, and artificial gravity to verify the applicability of ground-based human-engineering design principles to space conditions. The eventual product of this research will be revised design criteria for controls and displays, and for the work areas in which the controls and displays are used in conjunction with hardware designed for extended spaceflight.

The specific research in this Experiment Group was identified in 14 critical issues generated during in-depth analysis of the following long-range NASA objectives:

1. Identify requirements and develop equipment and procedures to assure man's effectiveness in performing scientific experiments, applications tasks, and vehicle operations.

2. Obtain data pertinent to the establishment of design criteria for manned systems required to perform over planetary flight time periods.

3. Develop operator equipment and technology for crew and cargo transfer, and for assembly and maintenance, internal and external to the space vehicle.

4. Develop the technology for habitable living areas for space vehicles.

An extensive long-term, well-coordinated and integrated program of ground research on advanced controls and displays is needed which utilizes ground simulation of space conditions. This research cluster identifies a long-term flexible evaluation program for flight verification of ground based findings and will permit repeated observations on a fairly large sample of astronauts under actual space conditions. This flight program will also permit in-orbit evaluation of very advanced control/display concepts applicable to planetary and other advanced missions. Such a program will assist in filling in the gaps in human engineering theory and resolving uncertainties regarding applicability of ground-based design criteria.

2. Background and Current Status

During and since World War II, a great deal of human engineering research has been conducted under the auspices of Government agencies (primarily the Air Force, Army, and Navy), industrial laboratories, and universities. The results of this research have been summarized in various texts, technical reports, and handbooks, some of which are listed in the references at the end of this synopsis.

In general, research on displays and controls has considered them as integral and interacting devices that (1) provide the operator with information about the status and operation of the subsystems under his cognizance for use in making decisions, and (2) give him the capability for communicating his decisions to the subsystems. Design of individual display and control components, and layout of a number of such components on panels has been thoroughly researched on the basis of human visual, psychomotor, and anthropometric capabilities. Criteria have been developed for selecting types of displays and controls for particular functions (e.g., auditory versus visual displays, pictorial versus numeric displays, hand-operated versus foot-operated controls, and pushbuttons versus toggle switches). Control forces, color and shape coding, control and display relationships and ratios, direction of control movement, and control feedback have all been investigated and results are summarized and published. Research on operator aids such as control quickening and predictor instruments, has provided the operator with a means of achieving more precise, accurate, and timely responses.

Two developments of the past decade impose additional demands on human-engineering research for controls and displays. In the first place, a number of new and rather unusual control and display devices have been developed, including interactive displays employing cathode-ray tubes and computer interfaces, plasma displays, light-emitting diodes, capacitance controls, and liquid crystal displays, all integrated very tightly with computers and providing a new and novel man-to-computer interface. These developments have occurred so rapidly that basic human-engineering experimentation has not had time to keep pace with them. The other development is man's venture into space, where he will, as in the past, require controls and displays to interact with the machines under his surveillance, but under all of the known and unknown conditions of extended spaceflight, such as weightlessness, centrifugally induced artificial gravity and altered day-night cycles. Much ground-based human-engineering experimentation is required on the new display and control concepts mentioned above, and an extensive evaluation program in space is needed to verify or revise traditional human engineering design criteria as they apply to spaceflight.

3. Description of Research
The basic hypothesis on which this research is based is that terrestrially developed human engineering design criteria for controls and displays are not directly applicable to long-term spaceflight and require some revision to account for weightlessness, artificial gravity, and other spaceflight conditions.

In general inflight verification of ground-based findings on the man to control/display interface will be accomplished through observation and crew evaluation during operational use of controls and displays at the mission work station. In addition this research cluster will require an experimental work station at which controlled human-engineering experiments can be conducted in a fashion similar to that used in human-engineering laboratories on Earth. The multiman work station will contain various controls and displays; be interconnected to a computer and data recording, storing, and transmitting facilities; and be capable of reconfiguration to permit different controls and displays to be mounted and to allow relocation of components on the panels.

Experimental sessions lasting about 30 minutes each will be carefully designed and ground-tested before flight. For each 90-day crew cycle, five such experimental sessions will be designed; they will differ in such features as type of work-station task, specific control and display components involved, and time stress of the task. Each experimental session will be repeated about every 10 days throughout a particular crew cycle.

At least three crewmen will participate as experimental subjects in each of these experimental tasks. These crewmen should be experienced in the kinds of flight, station monitoring, and experiment operations associated with the particular control and display configurations.

Measurements of task times, reaction times, and errors will be automatically recorded by the instrumentation associated with the experimental work station. Subjective comments of the crewmen subjects in evaluating the particular configuration will also be recorded.

One specific experiment within this research cluster was identified and described in detail under NASA contract NAS1-9248 "Requirements Study for a Biotechnology Laboratory for Manned Earth Orbiting Missions." It was designated in that study as

2-111 Advanced controls and displays

and is described briefly in Appendix H of this report.

4. Impact on Spacecraft
The experimental control and display station will occupy a volume 8 ft wide, 7 ft high, and 6 ft deep (336 cubic feet). This volume,

includes provisions for ancillary equipment and space occupied by the operator. The weight is estimated at 750 lb. Expendables included in the weight figure are TV magnetic tape and paper for a graph readout. Maximum power will be 500 w and the average will be 350 w.

The experimental work station will be utilized 60 hr per 90-day crew cycle for conduct of experimental sessions (120 sessions of 30 min each). An additional 45 min of preparatory activity and terminating activity is required for each experimental session, a total of 90 hr per 90-day cycle.

Crew time chargeable to this experiment group per 90-day crew cycle is allocated as follows:

Experimental Subject	70 hr
Experimenter (including experiment preparation)	144 hr
Work-Station Maintenance	4 hr
Communications	25 hr

5. Required Supporting Research and Technology
None

6. References

1. L.J. Fogel. Biotechnology: Concepts and Applications. Prentice-Hall, Inc., Englewood Cliffs, 1963.

2. Kennedy, J.L., L.C. Mead, D.B. Devoe, and D.E. Johannsen. Handbook of Human Engineering Data. NAV EXOS-P-643, U.S. Naval Training Device Center, 1952.

3. E. McCormick. Human Factors Engineering, Second Edition. McGraw-Hill, New York, 1964.

4. C.T. Morgan, A. Chapanis, J.S. Cook, III, and M.W. Lund (editors). Human Engineering Guide to Equipment Design. McGraw-Hill Book Co., Inc., New York, 1963.

5. P. Webb (editor). Bioastronautics Data Book. NASA-SP-3006, Scientific and Technical Information Division, National Aeronautics and Space Administration, 1964.

6. Personnel Subsystems Design Handbook. AFSC DH 1-3, 1 January 1969.

7. W.E. Woodson and D.W. Conover. Human Engineering Guide for Equipment Designers. University of California Press, Berkeley, 1964.

8. C.A. Baker and W.F. Grether. Visual Presentation of Information. USAF WADC TR 54-160, August 1954.

9. J.H. Ely, R.M. Thompson, and J. Orlansky, Design of Controls. Chapter VI of Joint Services Human Engineering Guide to Equipment Design. USAF WADC TR 56-172, November 1956.

10. Earth Orbital Experiment Program and Requirements Study Scientific and Technological Objectives. NASA Langley Research Center, Hampton, Virginia, July 28, 1969, L13-9852.

Critical Issues Addressed By Research Cluster

1-MM-1

CONTROLS AND DISPLAYS

1.1.2.1.2.10
What are the design requirements for controls and displays associated with operator, maintenance, and scientific investigation tasks?

1.1.2.2.1.1
How valid are traditional control/display design principles under conditions of long-duration spaceflight?

1.1.2.2.1.2
How is man's capability to handle information affected by the amount and type of data presented under conditions of long-duration spaceflight?

1.1.2.2.1.3
How effective are nonvisual displays in presenting status, trend, and alerting information?

1.1.2.2.1.4
What is the maximum capacity of the man-display combination for time sharing?

1.1.2.2.1.5
What display characteristics are incompatible with crew performance capabilities?

1.1.2.2.1.6
How can man's capabilities for communicating with computers be enhanced by optimum controls and displays?

1.1.2.2.1.7
What is the optimum combination of alpha and numeric symbology for CRT displays in long-duration spaceflight?

1.1.2.2.1.8
What are the spacecraft support requirements for various types of displays and controls?

1.1.2.2.1.9
What is optimum spacecraft ambient lighting for use with electroluminescent displays?

1.1.2.2.1.10
How can time-shared displays be used to reduce space and power requirements while enhancing crew performance?

1.1.2.2.1.11
How can nonessential indications on displays be eliminated?

1.1.2.2.1.12
What is the optimum mix of situation displays and discrete indicators?

1.1.2.2.1.13
What are the design requirements for a device to permit crew members to evaluate photographic data on board and to edit, crop, or reject prior to transmission?

1.1.2.2.1.14
What is the optimum arrangement of controls and displays at a single work station to permit control of a number of experiments, subsystem operations, maintenance actions or vehicle control?

1.2.1.7.1.1
What kind of CRT display systems would be adaptable to space station data retrieval problems?

1.2.1.7.1.2
What advantages could be derived from color CRT for output data discrimination, particularly for analog curves?

1.2.1.7.1.3
What size CRT data retrieval display(s) (large screen for simultaneous group observance or personal small units) would be required?

1.2.1.7.1.6
What mechanical or electronic overlay grids would be required for the CRT displays?

EARTH ORBITAL EXPERIMENT PROGRAM AND REQUIREMENTS STUDY

MANNED SPACEFLIGHT CAPABILITY

RESEARCH CLUSTER—1-MM-2
LOCOMOTION AND RESTRAINT

C-1- 160

RESEARCH CLUSTER SYNOPSIS—MANNED SPACEFLIGHT CAPABILITY
1-MM-2
Locomotion and Restraint

1. Research Objectives

The objectives of the locomotion and restraint research cluster are to identify requirements, and to develop procedures and equipment that will enable man to translate in space as well as restrain himself in a space environment. This research cluster will provide quantified data on locomotion and restraint areas necessary for design requirements, procedures, and equipment evaluation. This experiment will fill the technical information gap that currently exists for types of locomotion aids (powered versus manual) that are most effective and practical for extended stays in space. Restraints will be utilized and evaluated in the same manner, with emphasis on the difference between zero-g and partial-g restraint requirements.

2. Background and Current Status

Locomotion and restraint equipment is currently being designed from a knowledge base that is limited. Early restraint devices (Mercury - Gemini) were akin to aircraft restraint mechanisms. These proved to be adequate, because the vehicles themselves were a portion of the restraint, with their small internal volume. Locomotion aids and mechanisms were not required on the Mercury flights or early Gemini flight. With the advent of Gemini EVA experiments, the need for limited locomotion and restraint equipment was recognized. The equipment provided the Gemini crews with a means of achieving EVA. The advent of Apollo saw the further development of both locomotion and restraint equipment. Restraints such as dutch shoes and the EVA maneuvering unit (gas reactant) were significant advances. The MOL program utilized KC-135 zero-g flight test data and underwater null-gravity experiment data to design locomotion and restraint devices. Fortunately much of this basic information is being utilized in the design of Skylab A, in which the validity of the design can be evaluated in quantifiable measurements. These measurements will be part of Skylab A experiments M-508 and 509. The extent of the Skylab A experiments is not adequate to fulfill the multiple need of prolonged flight under zero-g and partial-g conditions. With the implementation of research cluster 1-MM-2, basic design criteria required for future design of locomotion and restraint equipment will be available for the design engineer

3. Description of Research

Experiments will be performed in space in a zero- or partial-g environment while utilizing specific locomotion and restraint devices. Carefully designed experimental tasks will be a part of the experiment setup. By varying the combinations of possibilities and the known tasks, it will be possible to achieve quantifiable data. The data to be gathered will be categorized in the following parameters:

1. Metabolic rate.

2. Impact force exerted by crewman.

3. Acceleration generated.

4. Elapsed time for task completion.

5. Record-Keeping

    a. TV time lapse.

    b. TV Real time.

    c. Task performance—Score index (as compared to Earth's 1 "G", standard).

The methods of measuring the above parameters are as follows:

1. Metabolism—A portable man-mounted metabolic analyzer is required, to analyze and transmit the results while the experiment is being conducted. The resultant data can then be compared to the time, type of locomotion and/or restraint or their combination, and task performance.

2. Impact—The force or pressures created by the crewman while performing specific tasks will be recorded on a predesignated basis. In general, pick-off points will be fixed as tether, locomotion aids (hand rails, grip aids, etc.), and restraint aids (pelvic restraints, toe holds, etc.). Other points will be located on the floor, wall, and ceiling panels that are instrumented to record force or pressure application. Torque or rotational force loads will be recorded as required for items such as hand holds, hand rails, handles, and knobs that have man-imposed rotational forces imposed upon them.

3. Acceleration—Acceleration pick-ups will have to be developed that are capable of being man-mounted. Upon activation, these pick-ups will send a signal to a man-mounted transmitter or transmit directly. The acceleration pick-ups will be capable of defining between positive and negative acceleration forces.

4. Elapsed Time—All designated tasks will be timed from a start and stop point that will be predetermined.

5. Record-Keeping

a. TV—All tasks will be recorded on time lapse TV. The tape will identify the task, subject, time, and location, and will be synchronized with other TV cameras that are recording the same event. Real-time TV recording will be available upon demand for specific tasks.

b. Task Performance—All tasks will have a score of correctness or degree of completion. All task scores will be recorded for analysis onboard or for dump to ground control.

c. Log Record—All crewmen will enter their subjective evaluation of tasks for this experiment in a questionnaire voice or keyboard entry log. The questionnaire will be brief, pertain to the specific task performed, and allow the crewman to record an "honest off the cuff" evaluation of the task performed.

The participation of the crewman has been includeded as an integral portion of the above experiment description.

One experiment within this research cluster was identified and described in detail under NASA contract NAS1-9248 "Requirements Study for a Biotechnology Laboratory for Manned Earth Orbiting Missions." It was designated in that study as

2-110 Evaluation of locomotion aids and techniques

and is described briefly in Appendix H of this report.

4. Impact on Spacecraft

The impact on the spacecraft is considered to be low to moderate. Electrical power is consumed by the TV equipment and associated data-transmission equipment. The power consumed is in direct proportion to the number of cameras in use. Camera use is a detail yet to be determined, as the exact experiment plan with number of reruns has not been determined.

All man-mounted sensors and transmitters (metabolism and acceleration) are battery powered. All recorders and exterior sensors are powered by the spacecraft. There are two areas of moderate impact—vehicle space and crew time. The space required to store and set up and assemble the experiment will occupy approximately 64 cubic feet. This figure will vary with the complexity and additions or deletions that the experiment investigator will decide upon. Crew time will be consumed by their utilization as test subjects. Interface impact between the experiment and the spacecraft will be low to moderate. All accommodations on both sides of the interface will be derived prior to launch. Provision will be made for in-flight interface modifications.

5. Required Supporting Research and Technology
Two SRT items are identifed:

1. Portable Metabolic Analyzer - To provide the subject freedom of movement, a portable metabolic analyzer is required. The analyzer will be mounted on the man, sample the breath, perform an analysis, and transmit a signal to a recorder outside the experiment area. The above is a problem of miniaturization and equipment accuracy and reliability.

2. On-Body-Accelerometer—To derive the acceleration and deceleration of various points on a subject's body, it will be a requirement to develop miniature accelerometers (motion sensors). In conjunction, a portable transmitter to transmit the sensed signal will also be required. The problems of miniaturization, accuracy, and reliability are also incurred with the on-body accelerometer. No special facilities or support should be required to augment this effort.

6. References

1. D.E. Havens, G.A. Johnson, and H.S. Jencks. Null Gravity Restraint Characteristics. McDonnell Douglas Paper WD 1240, April, 1970.

2. Otto F. Trout, Jr., and Paul R. Hill. Human Work Performance in Space. Paper presented at Second National Conference on Space Maintenance and Extravehicular Activities, Las Vegas, Nevada, 1968.

3. Streimer, Springer, and Tardiff. Human Output Characteristics During Specific Task Performance in Reduced Traction Environments. Human Factors, Vol. 6, 1964, pp. 121-126.

4. Summary of Gemini Extravehicular Activity. NASA SP-149, 1967.

5. C.B. Nelson. Simulation of Package Transfer Concepts for Saturn I Orbital Workshop. Paper presented at Second National Conference on Space Maintenance and Extravehicular Activities, Las Vegas, Nevada, August 6-8, 1968.

6. Experiment Requirements Document for Foot-Controlled Maneuvering Unit (Experiment T020). Proposed experiment for Skylab, ERD-T020 NASA, January 20, 1970.

7. A.E. Wiedell and W.H. Tobey. A Six Degree of Freedom Simulation Technique for Evaluating Space Mobility Aids and Tasks. Paper presented at Second National Conference on Space Maintenance and Extravehicular Activities, Las Vegas, Nevada, August 6-8, 1968.

8. D.G. Norman and E.S. Miller. EVA Force Emission Capability in Simulated Zero Gravity. Paper presented at Second National Conference on Space Maintenance and Extravehicular Activities, Las Vegas, Nevada, August 6-8, 1968.

9. Experiment Integration Requirements Document for Astronaut EVA Hardware Evaluation (Experiment M 508). Proposed experiment for Skylab, NASA, June 30, 1969.

10. Experiment Integration Requirements Document for Astronaut Maneuvering Equipment (Experiment M 509). Proposed experiment for Skylab, NASA, June 30, 1969.

Critical Issues Addressed By Research Cluster

1-MM-2

LOCOMOTION AND RESTRAINT

1.1.2.2.2.1
What is metabolic cost of work under various conditions of locomotion and restraint?

1.1.2.2.2.2
What are the acceleration profiles under various locomotion conditions?

1.1.2.2.2.3
How are crew dexterity, ability to apply forces, reach envelopes, visual span, and maintenance ability affected by various restraint techniques?

1.1.2.2.2.4
What are the restraint and locomotion requirements for partial-G compared with zero-G?

1.1.2.2.2.5
What is optimum restraint method for extended-duty work station?

1.1.2.2.2.6
How is sleep effectiveness affected by various sleep-station restraint methods?

1.1.2.2.2.7
What are the advantages and disadvantages of powered versus unpowered locomotion devices in terms of metabolic cost, encumbrance to crew activities, accuracy of path, control of acceleration and deceleration, safety from personal injury, or equipment damage?

1.1.2.2.2.8
How do various restraint devices compare in terms of demands on crew time?

1.1.2.2.2.9
What spacecraft support requirements are imposed by the various restraint and locomotion techniques and equipment?

1.1.2.2.2.10
What are the dynamics of a tethered crewman for various tether lengths?

1.1.2.2.2.11
What is optimum size and shape for cargo items to be transported in space by crewman using various locomotion techniques?

1.3.1.4.1.1
What are the various passive mobility aids required to support man's logistic operations in EVA and IVA such as body restraints, hand holds, design and location of rails and cables, use of Velcro, magnetic devices, or other restraints allowing maximum body usage and what are their peculiar design requirements?

1.3.1.4.1.2
What are the design requirements for mechanical devices which man can use to move and still maintain some degree of body restraint in order to exert force. Consider articulated and extendable devices.

1.3.1.4.1.3
What are the design requirements for: (a) Powered devices in IVA operations in order to transfer man or cargo and supplies to various attached modules. Consider rails, cables and conveyor systems.

(b) Powered devices in EVA operations in order to move man to the work area or element. Consider backpacks, taxi modules, and hand-held thrusters. What are the best design features for these units in terms of mobility, station keeping, restraint devices, storage areas, operational radii ----

1.3.1.4.1.4
What are the design requirements for remote control units in order to (a) deploy and position transfer aids such as rails or cables, (b) acquisition and restraint of satellites or experimental modules, and (c) unloading and transfer of cargo.

1.3.2.2.4
What motion aids are needed to allow man in IVA or EVA conditions to reach the space station critical areas:

1. Passive locomotion aids such as handrails, cables, handholds, etc.

2. Powered aids such as: Backpacks (scooters), hand held thrusters, small transfer modules (taxis), large transfer modules (buses).

3. Mechanical aids: articulated arms, extendable arms and booms.

EARTH ORBITAL EXPERIMENT PROGRAM AND REQUIREMENTS STUDY

MANNED SPACEFLIGHT CAPABILITY

RESEARCH CLUSTER–1-MM-3
HABITABILITY

C-1-167

RESEARCH CLUSTER SYNOPSIS—MANNED SPACEFLIGHT CAPABILITY
1-MM-3
Habitability

1. Research Objectives

The Habitability research cluster has as its ultimate objective the identification of design features or requirements that provide the optimum in architecture, environment, mobility, restraint aids, food and water management, personal hygiene and housekeeping, and off-duty facilities and activities. These design requirements will be utilized to provide the surroundings and environment in which experimenters must live and work during long-term space missions. These objectives will be achieved through evaluation of crew usage of habitable areas that include functional work, living, maintenance, and recreation provisions. To validate the experiments, the crew will be monitored while performing tasks to measure crew acceptance, area size and volume, effect upon attitude and mood, work efficiency, and desirability of change in arrangement and color scheme.

Included in this research cluster is research directed to 18 critical issues listed under the headings of Space, Environment, and Personal Support. These headings, and subsequent critical issues, were generated through analysis of the NASA long-range objective in the Man-Systems Integration Program Habitability subarea, which states, ". . . to develop methods and design criteria to produce habitable living areas in space vehicles."

Objective data will be derived from multiple experiment runs in zero-g and artificial-g conditions utilizing the same crew subjects. Habitability features to be assessed will be those identified as being the most acceptable on the basis of ground-based simulation and previous spaceflight. It is extremely important that considerable ground-based investigation be performed prior to space flight verification.

2. Background and Current Status

It is intended that the results of this research cluster be used by NASA and industry personnel to assist in the design and layout of future space vehicles, definition of equipment requirements, establishment of habitability requirements, and establishment of habitability guidelines that are proportional to length of mission.

In past manned space programs, valuable data have been accumulated on the acceptability of the habitability features, although design for optimum habitability has not been stressed because of over-riding engineering objectives of these programs. This approach has been successful due to two factors: (1) the crews have been highly motivated and as such have endured hardships ordinarily considered unacceptable, and (2) the duration of the mission has been short enough to permit a motivated endurance by the crew.

Our current knowledge of the subject of habitability is derived from ground-based studies of an experimental nature and operational, manned spaceflights. This information base comes from four major sources. (1) University laboratories and industry have conducted classical studies that have supplied a habitability baseline established prior to any consideration of space environment. (2) Closed environment or chamber runs have produced additional information that has significantly enriched the long-standing established baseline mentioned above. While the information on habitability has been well defined and documented, it has necessarily lacked elements of validity. Typical of these elements are: total isolation, actual communication break, zero-g, unprogrammed stress elements, and purpose of mission, found only in an actual self-contained mission. (3) Data retrieved from the Ben Franklin - Deep Drift Project, Tektite I, and Tektite II have provided, and will provide, supplementary information to enhance the current literature. (4) Data derived from manned spaceflight. The effect upon man by his habitable environment can be determined to a limited degree in closed chamber runs and to a much greater degree in free vehicles such as the Franklin and Tektite. However, it is agreed that the actual space environment of vacuum, extreme temperature changes, weightlessness, artificial-g effects, total isolation, crew interdependency, and other associated stresses can be best evaluated under the real conditions in space.

3. Description of Research

Quantitative data will be derived in four areas of habitability: (1) Space, (2) Environment, (3) Personal Support, and (4) Learning and Adaptation. Space-based research will attempt to provide answers to questions regarding general habitability through the measurement of three basic parameters. These three parameters are (1) physical health, (2) work efficiency, and (3) crew attitude and motivation. Measurements will be taken in various areas of these three parameters. Controls or experiment setup will be preprogrammed and will be designed to produce quantitative objective test results. Variations in the basic experimental setups will be provided to assist in the evaluation of the parameter and to provide direct correlation to a specific critical issue. As an example, a predetermined work load will be assigned to a specific crewman; the time to perform the controlled task, energy expended, light level, training required, and other significant facts concerning the control task as related to an Earth environment and performance base will be known. The control task will be performed by the assigned crewman, and output will be measured with one measurable variable being imposed per experiment run to the extent possible. The parameters to be varied will be chosen at the time of the detailed experiment design.

The cross reference of tasks and control of the variables to be imposed upon the tasks are the most important factors in the success of the habitability experiment. The experiment will commence with activation of the TV cameras and will continue throughout the mission. The experiment will not interfere with daily routine and planned crew achievement as the work will become an integral part of the experiment design. The reconfiguration of quarters or specific areas will be on a planned basis as will the crew work rotation or task assignment. It is desired that the experiment not be identified as such by the crew, but become an integral part of their daily living activity on a noninterference basis. The experiment designer must strive to achieve this end. Intimate knowledge of the mission purpose and time line of crew activities are essential to adequately achieve this goal.

Three experiments within this research cluster were identified and described in detail under NASA contract NAS1-9248 "Requirements Study for a Biotechnology Laboratory for Manned Earth Orbiting Missions." These were designated in that study as 2-108 Off-duty activities and facilities, 2-112 Advanced personal hygiene concepts, and 2-116 Reconfigurable interior configurations and decor and are summarized in Appendix H of this report.

4. Impact on Spacecraft

The impact of this research cluster consists mainly of measurement equipment and such expendables as magnetic tape. Two remotely controlled TV cameras with pan-tilt and zoom heads will be required to provide TV coverage. The total weight of these cameras is 12 lb and the volume is 0.75 cu ft. Each TV camera will require 4 w of power when operating. The total operating time for the 90-day crew cycle is estimated at 90 hours. Two cameras will be operating during the 90 hours of operating time. The cameras will operate at a rate of one frame every 3 seconds. A total of nine 2400-ft rolls of magnetic tape will be required per cycle.

Two recording microphones, each weighing 0.5 lb, occupying 0.01 cu ft, and consuming 1 w, are required to record crew dialogue and comments. Operating time for each microphone is 90 hours. Control equipment for the videotape recording in the form of a console, monitor, control, and switching circuitry will be housed in a volume of 4 cu.ft, weigh 80 lb, and require 80 w of power. Operating time of this equipment is approximately 100 hours.

Crew participation is required for all recording and test sessions. Crew training is minimal as crew participation and involvement are minimal. Each crew member will complete a habitability questionnaire by means of voice log or keyboard entry every 10 days.

A total of 180 minutes per crewman will be consumed on the questionnaires during one crew cycle.

5. Required Supporting Technology Development

Techniques and procedures must be generated and perfected in a ground simulation of this experiment. Specific habitability experiments and other experiments must be coordinated and time shared as applicable to extract a maximum data base in the most efficient manner. A time line to accomplish this will be subjected to a dry run prior to acceptance.

It is required that techniques be developed for the evaluation of video and audio tapes as recorded during the habitability experiment. It is also required to provide a process or tool that permits a graded evaluation of all aspects of habitability.

6. References

1. S. Deutsch. First National Symposium on Habitability; Vol. III, May 1970.

2. S. Deutsch. Tektite: A Study of Human Behavior in a Hostile Environment. Science, September 1969.

3. W.L. Jones. Habitability Factors in Long Duration Space Missions. Prepared for the Foundation of Space Biology and Medicine USA-NASA/USSR - Academy of Sciences Project, January 1970.

4. F.A. Muckler. Human Factors Problems. Paper presented at the Space Station/Base Experiment Data Processing Information—Exchange on Requirements and Design Guidelines Workshop, November 1969.

5. W. Snaith and R. Lowey. Habitability Study, Earth Orbital Space Stations. Prepared for NASA December 1968.

6. Human Engineering Design Criteria Study, NASA Contract NAS8-11256, January 1966.

7. Aerospace Medicine and Human Research, Crew Habitability and Protection Subsystem. NASA/MDAC Supporting Research and Technology Review Report, March 1970.

8. Engineering and Architectural Study for Extraterrestrial Architectural Design, RFP No. MSC JC421-M68-70-99P. February 1970.

Critical Issues Addressed By Research Cluster

1-MM-3

HABITABILITY

1.1.2.2.3.1.1
What is effect of time in orbit on volume requirements?

1.1.2.2.3.1.2
How do volume, configuration, and privacy provisions affect crew adjustment?

1.1.2.2.3.1.3
What is the effect on crew performance and adjustment of changing volume and configuration periodically?

1.1.2.2.3.2.1
How does sleep station design affect crew performance and adjustment?

1.1.2.2.3.2.2
What level of artificial gravity is optimum?

1.1.2.2.3.2.3
How does illumination affect crew performance and adjustment?

1.1.2.2.3.2.4
What effect do color and decor have on crew effectiveness?

1.1.2.2.3.2.5
What is optimum comfort criteria (e.g., temperature, humidity, air flow)?

1.1.2.2.3.2.6
How does the acoustic environment affect crew performance and adjustment?

1.1.2.2.3.2.7
What equipment and procedures are optimum for crew health maintenance?

1.1.2.2.3.2.8
How do crew attitudes toward habitability features change over time in long-duration spaceflight?

1.1.2.2.3.2.9
How effective is preflight training in conditioning crews to accept habitability features?

1.1.2.2.3.2.10
What are the physiological and psychological requirements for frequency of use of habitability provisions?

1.1.2.2.3.2.11
What are the spacecraft support requirements imposed by various habitability features?

1.1.2.2.3.3.1
How do nutritional requirements change over time in space?

1.1.2.2.3.3.2
What is optimum in-flight physical fitness program?

1.1.2.2.3.3.3
How do provisions for recreation and leisure affect crew performance and adjustment?

1.1.2.2.3.3.4
What are optimum personal-hygiene facilities?

EARTH ORBITAL EXPERIMENT PROGRAM
AND REQUIREMENTS STUDY

MANNED SPACEFLIGHT CAPABILITY

RESEARCH CLUSTER—1-MM-4
WORK/REST/SLEEP CYCLES

C-1-173

RESEARCH CLUSTER SYNOPSIS—MANNED SPACEFLIGHT CAPABILITY
1-MM-4
Work/Rest/Sleep Cycles

1. Research Objectives

The research objectives of the Work/Rest/Sleep Cycle Research Cluster are to (1) determine the effect of changes in length and time of rest on getting a good nights rest in space, (2) determine the time required to awaken and react to emergencies, and (3) develop optimum work/rest/sleep cycles for long-duration missions. These objectives will be realized by measurement and evaluation of various sleep patterns and determining the time required to awaken and react to emergencies.

The research included in this Research Cluster is addressed to 13 critical issues categorized under the headings of Rhythms and Cycles, Sleep, and Work/Rest, which were derived from a detailed analysis of a NASA long-range objective in the Man-System Integration Program subarea of Man-Machine Research ". . . to quantify human capabilities for performing physical and mental work as an operator and maintainer of space systems and equipment, and as a scientific investigator, and provide data for decisions on the appropriate man/machine mix."

Empirical data are needed on the performances of multiple subjects in space. Analytic mission and system data are neded on a continuing basis to establish on/off schedules for different types of long-duration missions.

2. Background and Current Status

Past spaceflight schedule variations have demonstrated some advantages from (1) maintaining consistency between prelaunch and mission rest/sleep schedules; (2) simultaneous sleep; (3) short sleep periods (naps) for needed rest prior to critical points in a mission. Flights generally have been for time periods of less than 2 weeks, near the Earth so ground personnel could monitor systems while crew members slept, and virtually free of collision threats that might require quick avoidance maneuvering reactions. The need for a continuous watch may increase as more self-sufficient spacecraft permit increases in mission length and variety of objectives.

Continuous watch requirements at the display/controls panel can be met by a sleeping operator if he can be awakened to react to emergencies through use of automatic alarms or signals. Detailed questions include the time available for him to awaken, interpret displays, and operate controls, versus the time and errors in his performance under those circumstances. Continuous watch for hull punctures can be maintained by a crewman asleep in his quarters if there is time for him to awaken, safely move to another pressure compartment as necessary to don a pressure suit, obtain a patch kit, and seal the leak.

This information may affect layout of crew quarters, location of emergency pressure suits, placement of repair kits, crew work schedules, and other similar activities.

3. Description of Research
The research in this Research Cluster will be a continuing long-range effort on different types of vehicles, with crews of different size and composition, and under different mission conditions. Using each subject as his own control, data will be recorded on circadian rhythm and diurnal cycles, length and depth of sleep, work on selected tasks when working a normal versus a shift type of schedule, and crewman responses to emergency type events when awakened from sleep.

Data will be collected on a non-interference basis while crewmen are performing normal mission activities, but in order to obtain the required data in various work/rest/sleep cycles, it will be necessary that the mission schedule have sufficient flexibility to vary work/rest cycles and sleep cycles. For the evaluation of circadian rhythm changes over time, biomedical and behavioral data such as cardiovascular activity, body temperature, metabolic rate, blood chemistry, fatigue, level of attention and concentration, and work efficiency will be collected on a continuing basis for ground analysis. Sleep data will be collected by a combination of EEG recording and subjective responses by crewmen. Data on emergency responses during sleep will be obtained by accurately measuring the reaction of crewmen when awakened from various depths of sleep in terms of time to respond to operational requirements.

Two experiments within this research cluster were identified and described in detail under NASA contract NAS1-9248 "Requirements Study for a Biotechnology Laboratory for Manned Earth Orbiting Missions." These were designated in that study as

2-113 Assessment of circadian rhythm changes

2-117 Sleep behavior

and are described briefly in Appendix H of this report.

4. Impact on Spacecraft
Impact on the spacecraft for this type of research is minimal, and similarly much of the data gathering will be accomplished on an observational, noninterference basis. The primary impact of this observational research will come from measurement equipment and such expendables as magnetic tape. The remotely

controlled TV camera volume is less than 1.5 cu ft and the weight is less than 40 lb. It requires 4 w of power while operating, and the total operating time for a 90-day cycle is estimated at 24 hours. This data gathering requirement can be shared with Research Cluster 1-BR-3, Complex Task Behavior.

The experiments toward determining whether a crew member can meet foreseeable emergencies without working a shift-type schedule will make use of the video tape equipment for 1 hour per subject per crew cycle or 6 hours for a crew of six. Other necessary equipment will include the use of an EEG recorder. The EEG analogue recorder (strip chart) will be no larger than 1 cu ft, weigh no more than 20 lb and require 50 w for 6 hr/mission for a 6-man crew. All crew members will serve 2 hours as subjects and 2 hours as observers per mission.

5. Required Supporting Research and Technology
Before accomplishing postlaunch sleeping-watch research, there is need for analytic research to identify the emergency tasks that man may have to accomplish immediately after being awakened: and there is need for detailed simulation of these tasks to establish experiment apparatus, protocols, and performance data on subjects.

6. References

1. I. Oswald. Sleeping and Waking. Elsevier, New York, 1962.

2. G.A. Peters and H.J. Dendle. Personnel Requirements in Manned Space Vehicles. Engineering Paper No. 931., Douglas Aircraft Co., Santa Monica, February 1960.

3. J.T. Ray, O.E. Martin, Jr., and E.A. Alluisi. Human Performance as a Function of the Work-Rest Cycle. No. 882, National Academy of Science, National Research Council, Washington, D.C., 1961.

4. R.E. McKenzie, B. Hartman, and D.E. Graveline. An Exploratory Study of Sleep Characteristics in a Hyprodynamic Environment No. 60-68, School of Aviation Medicine. Brooks AFB, Texas, October 1960.

5. N. Kleitman and E. Kleitman. Effect of Non-Twenty-Four-Hour Routines of Living on Oral Temperature and Heart Rate. Journal of Applied Physiology, Vol. 6, 1953, pp 283-291.

6. G.T. Hauty. Human Performance in Space; in Man in Space, K.F. Gantz, Ed., Duell, Sloan, and Pearce; New York, 1959.

7. Earth Orbital Experiment Program and Requirements Study Scientific and Technological Objective, L13-9852. NASA Langley Research Center, Hampton, Virginia, July 28, 1969.

Critical Issues Addressed by Research Cluster

1-MM-4

WORK/REST/SLEEP CYCLES

1.1.2.2.4.1.1
How do circadian rhythms change in long-duration spaceflight?

1.1.2.2.4.1.2
What is the effect of circadian changes on crew performance?

1.1.2.2.4.1.3
How can adverse effects of circadian changes be prevented or ameliorated?

1.1.2.2.4.2.1
What is the effect of time in orbit on sleep requirements?

1.1.2.2.4.2.2
How is sleep effectiveness affected by external factors (e.g., noise, acceleration, illumination)?

1.1.2.2.4.2.3
How effective are short sleep periods (4 hours to catnapping) in meeting sleep needs in long-duration spaceflight?

1.1.2.2.4.2.4
What are the advantages and disadvantages of simultaneous sleep?

1.1.2.2.4.2.5
What is the effectiveness (or need) of artificially induced sleep?

1.1.2.2.4.2.6
What is the pattern of sleep stages over time in orbit?

1.1.2.2.4.3.1
What is the optimum on-off work schedule in long-duration spaceflight?

1.1.2.2.4.3.2
How do work/rest requirements change over time in long-duration spaceflight?

1.1.2.2.4.3.3
What is the effect on crew performance and adjustment of the altered day/night cycles of space?

1.1.2.2.4.3.4
How long does it take crew members in space to adjust to altered day/night cycles, and what is the pattern of individual differences?

EARTH ORBITAL EXPERIMENT PROGRAM
AND REQUIREMENTS STUDY

MANNED SPACEFLIGHT CAPABILITY

RESEARCH CLUSTER–1-MM-5
PERFORMANCE AIDS

C-1-178

RESEARCH CLUSTER SYNOPSIS—MANNED SPACEFLIGHT CAPABILITY
1-MM-5
Performance Aids

1. Research Objectives

This research cluster has as its objective the acquisition of in-space data on the man-machine interface with equipment designed to assist man in performing tasks in maintenance and repair, experiment operations, and data handling. The specific experiments will evaluate man's capabilities and limitations and provide design criteria for tools, remote manipulators, optical aids, and job aids such as checklists and computer aids.

19 critical issues are addressed by the research included in this research cluster. These critical issues were derived by a detailed analysis of the following NASA long-range objective extracted from the Man-Systems Integration program subarea, Operator Equipment and Technology: ". . . to develop equipment, tools, and techniques for rescue, crew and cargo transfer, assembly, maintenance, and repair, both IV and EV (worksite aids, visual aids, tools for weightlessness, remote manipulators)."

A comprehensive, evolutionary program of research is needed to evaluate performance aids as they become available through ground development efforts or as they are improved as a result of experience in space.

2. Background and Current Status

Performance aids are those hardware and software devices provided to augment, extend, reinforce, and enhance man's capabilities to perform operational maintenance and experimental space activities. In this research cluster performance aids are restricted to four types: tools, remote manipulators, optical aids, and job aids such as checklists and computer aids.

Tools for space maintenance and repair is the area of performance aids which has received the most research and development attention in the space program to date. Several of the NASA centers (particularly Langley Research Center and Marshall Space Flight Center) have done a number of in-house and contracted studies on tool identification, design, and test. Hardware and state-of-the-art surveys have been made and tools for space are being cataloged (by Ames Research Center). Of the manually operated hand tools and power tools developed, none have yet been rated as flight operational.

Remote manipulator development for ground applications has a long history. The Argonne National Laboratory since 1947 has conducted extensive development and tests of devices for use in radioactively hot cells. The Aerospace Medical Research Laboratories at Wright Patterson Air Force Base began a program of research in 1959 to determine human factors aspects of design and use of remote handling equipment. The Jet Propulsion Laboratory of NASA has for the past few years concentrated on remotely controlled equipment to be used on the lunar surface.

The Surveyor program with its Moon-Digger has demonstrated the feasibility of remotely collecting samples and even of remote maintenance. Time and motion studies by Argonne National Laboratories have shown that simulated space tasks can be accomplished by a shirt-sleeve operator using a Master-Slave manipulator about equally as well as an astronaut in a pressurized spacesuit.

Optical aids for enhancement of man's visual capabilities in space have received little attention to date. Protective optical devices for filtering harmful light energy have been developed for spacesuit helmets. Ames Research Center is developing design criteria for an electro-optical light filter device and is developing means of reducing angular sighting error by astronauts when making a sextant sighting. Experiments are being conducted which employ an extended range of stimulus conditions, including various target-to-background contrast ratios and an adequate number of observers. Charts and nomographs are being developed for correcting navigational sighting errors in the high luminance environment of space.

Checklists and computer aids including hard copy, film-projected and computer-generated checklists, schematics, and other Technical Order type data have received considerable attention from the human engineering laboratories at Wright Patterson Air Force Base, Navy electronics and maintenance research centers, and from various NASA centers. For extended spaceflight, one of the major problems is determining the specific data to be stored for later retrieval. Another is the problem of communicating with computers to retrieve such data. The NASA Electronics Research Center was interested in determining the parameters that govern the utilization of spoken English as a means of communicating with computers and were investigating provisions for rapid information retrieval from computers to assist space vehicle crews in making decisions and solving problems. In this respect an interesting research problem involves the relative value of color in interactive displays.

3. Description of Research

This research cluster is divided into the following four subgroups: (1) tools, (2) remote manipulators, (3) optical aids, and (4) job aids. Selected crewmen will serve as subjects with three crewmen performing each experimental task. Experiments will be performed over the total length of mission cycles in order to identify any degradation associated with mission duration. Individual experiments within this cluster will continue over several years of spaceflight, changing only in specifc configurations of performance aids as advanced aids become available. Data accumulated in Skylab A experiments in which performance aids are used will serve as a point of departure for the experiments in this research cluster.

Tool experiments (both IVA and simulated EVA) will be conducted using either operational equipment or task boards incorporating components which can be removed and replaced, fasteners, and electrical and fluid lines. If task boards are used, they will be instrumented with strain gages for sensing forces and torques and connected to bridge circuits for converting strain gage displacement into electrical signals. Experimental tasks, each for a specific tool/procedure combination and each requiring an arbitrary task time of 30 minutes, will be designed, extensively tried out in ground simulations, and incorporated into the flight crew training program. During flight each experimental task will be scheduled for at least four repetitions, separated by time intervals of 10 to 30 days. Each task will be performed suited-pressurized, suited-unpressurized, and unsuited. Task times, errors, and metabolic cost will be obtained and forces and torques will be automatically recorded. Subject and observer comments will be obtained after each measurement session.

Remote manipulator experiments will use various types of electrical remote manipulators. Early experiments will be performed with a panel-controlled manipulator and advanced experiments with bilateral master/slave manipulators. Experiment sessions will utilize task boards (or operational equipment as appropriate) upon which subjects will perform the tasks directly (space suited and unsuited) and remotely from a panel or master position. Performance will be compared on measurements of task time, errors, energy expenditures, difficulties encountered, power expended, and transmission time delay effects.

Optical aids experiments will be performed concomitant with operational activities and other experimental activities and will include research with aids such as marking devices on spacecraft windows, telescopes, and devices for reducing amount and type of incident light reaching the astronaut's eyes. Measurement sessions will be scheduled to permit evaluation of each device a minimum of three times within a 90-day period. Parameters to be measured include number of targets detected, number of targets identified, tracking accracy, visual resolution, speed of target acquisition. Data will be collected primarily from subject reports.

Job aids experiments will evaluate the crewmen interface with computer stored, film stored, hard copy, and mechanical job aids. The research is addressed to evaluation of the adequacy, availability, and usability of the aids; and to measurement of the effect that using the aids has on crew task time and error. Measurements will be made while crewmen are using the job aids in mission and experimental activities.

Experimental Data for this research cluster will be collected and collated onboard and either telemetered or returned to ground by logistics vehicle for analysis.

Two experiments within this research cluster were identified and described in detail under NASA Contract NAS1-9248 "Requirements Study for a Biotechnology Laboratory for Manned Earth Orbiting Missions." These were designated in that study as 2-114 "Maintenance Activities and Tool Evaluation" and 2-115 "Evaluation of Man-remote Manipulator Interface" and are described briefly in Appendix H of this report.

4. Impact on Spacecraft
Volume, weight, and power impacts are tabulated below.

Equipment or Facility	Weight (lb)	Volume (cu ft)	Average Power (w)	Operating Time per 90-day Crew Cycle (hr)
Task board	100	10.0	30	19.5
Metabolic analyzer	35	3.3	25	10.5
Heart rate (Cardio-tachometer and ECG)	4	0.3	6	9.0
Timer	(spacecraft installed equip.)		1	37.5
TV camera	6 ea	0.3 ea	4 ea	37.5
Photo lights	10 ea	1.0 ea	200 ea	37.5 max
Video monitor and recorder	100	5.0	100	37.5
Audio recorder	8 ea	0.4 ea	10 ea	8.5
Remote manipulator				
Panel controlled	80	10.0 (stowed)	20	7.5
Master/slave	200	15.0 (stowed)	80	7.5
Tracking device	5	0.3	10	2.25
Free volume at task board	-	200 to 300 (140 cu ft if remote manipulator not used)		

Crew time requirements for a 90-day crew cycle in which all subgroup experiments are run is summarized below:

	Time/hr			
Subgroup	Experiment Setup	Experimental Subject	Experimenter	Data Logging
Tools	6	12	12	2
Remote Manipulators	3.75	7.5	7.5	1.25
Optical Aids	2.25	6.75*	0	2.25
Job Aids	3.0	18.0*	18.0	3.0

(*)Time not chargeable to this research cluster.

5. Required Supporting Research and Technology
Research and development is required in the following areas:

1. Development of universal, flexible task boards. Task boards are required for a variety of space experiments on evaluation of human capabilities. Such task boards should be capable of being reconfigured in space so that they can serve their function over extended time periods while a given spacecraft is in orbit. An ideal situation would be to have one configuration of a task board capable of serving a number of different experiments over time periods as long as 10 years.

2. Tool Selection Program. A ground-based space simulation effort is required to make preliminary evaluations of various powered and unpowered tools for a number of different space maintenance applications so that the tools selected for space experimentation are the best candidates.

3. Development of space version of a bilateral/master/slave electric remote manipulator. Ground devices are too cumbersome, too heavy, and require high power expenditures. A development effort to optimize a remote manipulator for a variety of space applications is necessary.

4. Development of optical aids for Earth surveys. For evaluation of man's capability to perform Earth survey's operations, it is desirable that the best possible types of optical aids be furnished. A development and flight test effort (using aircraft) is necessary.

6. References

1. R.H. Blackmer, A. Interian, and R.G. Clodfelter. The Role of Space Manipulator Systems for Extravehicular Tasks. Second National Conference on Space Maintenance and Extravehicular Activities, Las Vegas, August 6-8, 1968, pp. IV. 2. 1 to 2. 18.

2. Space Tool Development, Vol. I, State of the Art Survey, NASA TM X-53725.

3. Space Tool Development, Vol. II, Priority List for Tool and Process Development, NASA TM X-53784.

4. Otto F. Trout, Jr., and Paul R. Hill. Human Work Performance in Space. Second National Conference on Space Maintenance and Extravechicular Activities, Las Vegas, August 6-8, 1968, pp. III-1-1 to III-1-8.

5. William N. Kama. Human Factors in Remote Handling. Project Rose Seminar, Germantown, Maryland, May 26, 1964.

6. Manned Optical Viewing from Space: A Review. Report MDC E0007, McDonnell Douglas Astronautics Company Eastern Division, St. Louis, Missouri, November 19, 1969.

7. Space Research, Directions for the Future, Appendix 8 to Chapter X, Medicine and Physiology. Some Characteristics of Man Pertinent to Spacecraft Design and Operations. Julien M. Christensen and Conrad L. Kraft. Report of a Study by the Space Science Board, National Academy of Sciences—National Research Council, Washington, D.C., February 1966, pp. 214-272.

8. W.E. Bradley. Telefactor Control for Space Operations. Astronautics and Aeronautics, May 1967, pp. 32-38.

9. Edwin G. Johnsen. Telesensors, Teleoperators, and Telecontrol for Remote Operations. IEEE Transactions on Nuclear Science, February 1966, pp. 14-21.

10. Alfred Interian and Donald Kusath. Remote Manipulators in Space. Astronautics and Aeronautics, March 1969, pp. 40-51.

11. Edwin G. Johnsen and William R. Corliss. Teleoperators and Human Augmentation, NASA SP-5047, December 1967.

12. George C. Keller. Man Extension Systems—A Brief Survey of Applicable Techniques and a Proposed Program, NASA TMX-6307. December 1967.

Critical Issues Addressed by Research Cluster

1-MM-5

PERFORMANCE AIDS

1.1.2.1.1.1.3.14
How effective are optical aids in enhancing visual acuity in long-duration spaceflight?

1.1.2.1.1.1.3.15
How is visual acuity affected by protective and filtering devices?

1.1.2.1.1.1.3.31
How is depth perception affected by protective and filtering devices?

1.1.2.1.1.1.3.44
How is peripheral vision affected by protective and filtering devices?

1.1.2.1.1.1.3.60
How is ability to identify complex visual patterns affected by protective and filtering devices?

1.1.2.1.2.12
How can on-board computers be used to assist in performance of operator, maintenance, and scientific investigation tasks?

1.1.2.1.2.14
What is the optimum method of storing, retrieving, and presenting reference data for operator, maintenance, and scientific investigation tasks?

1.1.2.2.5.1.1
What are the design and storage requirements for tools on long-duration spaceflight?

1.1.2.2.5.1.2
How effective are multipurpose tools, special tools, and standard 1-G tools, and how can tool requirements be reduced?

1.1.2.2.5.1.3
What are prime equipment design requirements imposed by tools and remote manipulators?

1.1.2.2.5.1.4
What are the dynamics of tethered tools in weightlessness?

1.1.2.2.5.2.1
What is the effect of the spaceflight environment on design requirements for remote manipulators?

1.1.2.2.5.2.2
How do task time requirements differ for direct versus remote manipulators?

1.1.2.2.5.2.3
What feedback is required for operators of remote manipulators?

1.1.2.2.5.3.1
What is relative value of visual versus auditory checklists in long-duration spaceflight?

1.1.2.2.5.3.2
How effective are computer performance aids?

1.1.2.2.5.3.3
How effective are various optical aids in enhancing performance?

1.2.1.1.3.13
What computer contributions can be made to mental recreational games during long space station tours of duty?

1.2.1.2.2.9
What are the requirements of an onboard scientific and recreational microfilm library, and what retrieval techniques will be utilized?

TABLE 1. LEGEND OF CODES USED IN CREW ACTIVITY MATRICES

Table 1 is an explanation of the codes used in the following matrices. The matrices summarize the inflight crew tasks required to conduct and support the research identified in the synopses.

TYPE OF ACTIVITY

0 - Not covered below

1 - Experimental subject

2 - Spacecraft operations

3 - Preexperiment equipment preparation

4 - Maintenance of equipment

5 - Conduct of experiment

6 - Evaluate intermediate results

7 - Direct observation of phenomena

8 - Data handling

9 - Communications; initiate and receive transmissions (telemetry, voice)

CREW SKILL

0 - No special skill required

1 - Medicine

2 - Biology

3 - Physiology

4 - Psychology

5 - Engineering

6 - Astronomy

7 - Physics

8 - Oceanography

9 - Forestry

10 - Agriculture

11 - Geology

12 - Meteorology

13 - Geography

14 - Cartography

15 - Hydrology

16 - Navigation

17 - Communications

18 - Radiology

19 - Instrumentation

20 - Photography

21 - Astronaut

22 - Other

Each code includes the first one or two digits describing the discipline and a second code letter describing level of skill: A for highest skill level (requires professional training with degree or advanced degree in discipline such as M. D.): B for semiprofessional, the traditional technician level requiring several years of training; C for technician level which requires some special training.

CREW ACTIVITY MATRIX

RESEARCH CLUSTER NO.	TASK DESCRIPTION	EXPERIMENT EQUIPMENT	TYPE OF ACTIVITY	PECULIAR ENVIRONMENTAL REQUIREMENTS	EXCLUSIVE	CREW SKILL	FREQUENCY	TASK TIME (MIN)	NO. OF CREWMEN	START	DURATION	TASK CONCURRENCY
1-MM-1 (1)	Configure control/display work station for specific experiment.	Experiment Console and Equipment.	3			19-C	3/Week	20	1	78	5 Years	
(2)	Retrieve applicable computer program and place on line.	———	3			19-C	3/Week	5	1	78	5 Yrs	
(3)	Checkout operation of work station, computer program, and data recording.	Console, Computer, TV, & Audio Tape.	3		✓	19-C	3/Week	10	1	78	5 Yrs	
(4)	Brief Experiment Subject	Instruction Material	5		✓	21-A	3/Week	5	1	78	5 Yrs	
(5)	Turn on Instrumentation	Console	5		✓	19-C	3/Week	1	1	78	5 Yrs	
(6)	Observe Conduct of Experiment.	———	5		✓	19-A	3/Week	30	1			
(7)	Evaluate Data Collection	———	8		✓	19-A	3/Week	0	1	78	5 Yrs	
(8)	Record Observations	Pencil, Paper, Tape Recorder.	8		✓	19-C	3/Week	0	1	78	5 Yrs	
(9)	Turn Off Instrumentation	Console	5		✓	19-C	3/Week	1	1	78	5 Yrs	
(10)	Reconfigure Experimental Work Station	Hand Tools, Plan, Bldg. Material	4			22-B	Yearly	8 Hours	2	78	5 Yrs	
(11)	Troubleshoot and Repair Experimental Equipment.	Test Equipment and Prints.	4		✓	19-B	Monthly	30	1	78	5 Yrs	
(12)	Periodic Maintenance (Clean, Adjust, Replacement of Components).	Maintenance Kit.	4			19-B	Weekly	20	1	78	5 Yrs	
(13)	Initiate Data Recording, Storage Printout.	———	8		✓	19-C	3/Week	Concurrent with Experiment	1	78	5 Yrs	
(14)	Evaluate Data Acquisition	———	6		✓	19-C	3/Week	" " "	1	78	5 Yrs	
(15)	Correct for Bad Data.	———	8		✓	19-B	As Needed	———	1	78	5 Yrs	
(16)	Initiate Transmission to Ground.	———	9			17-B	Daily	25	1	78	5 Yrs	
(17)	Perform Experimental Control/Display Tasks.	Experiment Console & Computer Program	1		✓	21-A	3/Week	30	1	78	5 Yrs	
(18)	Record Subjective Comments.	Tape Recorder.	8		✓	19-B	3/Week	10	1	78	5 Yrs	

RESEARCH CLUSTER NO.	TASK DESCRIPTION	EXPERIMENT EQUIPMENT	TYPE OF ACTIVITY	PECULIAR ENVIRONMENTAL REQUIREMENTS	EXCLUSIVE	CREW SKILL	FREQUENCY	TASK TIME (MIN)	NO. OF CREWMEN	START	DURATION	TASK CONCURRENCY
1-MM-2 (1)	Configure Experiment Area to Accept Locomotion and Restraint Experiment.	Tool Kit, Exper. Maze, Locomotion & Restraint Equipment.	3		X	19-C	2/90 Days	8 Hrs.	1	77	3 Yrs	
(2)	Checkout Equipment, Test and Recording Equipment	On-Board Recording & Ck.Out Eqpt.	3		X	19-C	2/90 Days	8 Hrs.	1	77	3 Yrs	
(3)	Fit Restraints and Locomotion Aids to Subject.	Tool Kit	3		X	19-C	8/90 Days	10 Mins	2	77	3 Yrs	
(4)	Brief Experimental Subject.	Instruction Material	5		X	21-A	8/90 Days	10 Mins	1	77	3 Yrs.	
(5)	Turn On Instrumentation	Test/Monitoring Console	5		X	19-C	8/90 Days	1 Min	1	77	3 Yrs.	
(6)	Observe Conduct of Experiment	————	5		X	19-A	8/90 Days	30 Mins	1	77	3 Yrs.	
(7)	Evaluate Observations	————	8		X	19-A	8/90 Days	0	1	77	3 Yrs.	
(8)	Record Observations	Pencil, Paper, Tape REcorder.	8		X	19-C	8/90 Days	0	1	77	3 Yrs.	
(9)	Turn Off Instrumentation	Test Console	5		X	19-C	8/90 Days	0	1	77	3 Yrs.	
(10)	Reconfigure Experimental Maze Complex.	Hand Tool Kit, Plan, Bldg. Mat'l	4		X	22-B	4/90 Days	2 Hrs.	2	77	3 Yrs.	
(11)	Troubleshoot and Repair Experimental Equipment.	Test Equipment & Prints (Plans)	4		X	19-B	As Required	30 Min	1	77	3 Yrs.	
(12)	Perform Maintenance (Clean, Adjust, Replace Components).	Maintenance Kit	4		X	19-B	As Required	0	1	77	3 Yrs.	
(13)	Initiate Data Recording, Storage, Printout.	Test/Recording Console	8		X	19-C	8/90 Days	Concurrent With Experiment	1	77	3 Yrs.	
(14)	Evaluate Data Acquisition.	————	6		X	19-C	8/90 Days	10 Min	1	77	3 Yrs.	
(15)	Correct for Bad Data.	————	8		X	19-B	------	10 Min	1	77	3 Yrs.	
(16)	Initiate Transmission to Ground.	————	9		X	17-B	Daily Per Run		1	77	3 Yrs.	
(17)	Perform Experimental Locomotion and Restraint Tasks.	Experiment Console and Plan.	1	Pressure Suit to be Donned as appropriate to Simulate Locomotion & Restraint Tasks Related to EVA While IV.	X	21-A	8/90 Days	30 Min	1	77	3 Yrs.	
(18)	Record Subjective Comments.	Tape Recorder.	8		X	19-B	8/90 Days	15	1	77	3 Yrs.	

CREW ACTIVITY MATRIX

RESEARCH CLUSTER NO.	TASK DESCRIPTION	EXPERIMENT EQUIPMENT	TYPE OF ACTIVITY	PECULIAR ENVIRONMENTAL REQUIREMENTS	EXCLUSIVE	CREW SKILL	FREQUENCY	TASK TIME (MIN)	NO. OF CREWMEN	START	DURATION	TASK CONCURRENCY
1-MM-3 (1)	Prepare and Configure Living and Working Areas as Required to Accept Habitability Experiment.	Experiment Plan, Tool Kit.	3		X	19-C	Once Per 90 Days	4 Hrs.	1	76	5 Yrs	
(2)	Checkout the Monitoring, Test, and Recording Equipment.	On-Board Recording & Checkout Equip.	3		X	19-C	Once Per 90 Days	60 Min	1	76	5 Yrs	
(3)	(Plan to be Updated by Ground Every 90 Days) Retrieve and Review Experiment Plan.	———	3		X	19-C	Once Per 90 Days	60 "	1	76	5 Yrs	
(5)	Turn On Instrumentation	Test/Monitoring Console.	5		X	19-C	1/10 Days	1	1	76	5 Yrs	
(6)	Observe Conduct of Experiment	———	5		X	19-A	1/10 Days	30 Min	1	76	5 Yrs	
(7)	Evaluate Observations	———	8			19-A	1/10 Days	0	1	76	5 Yrs	
(8)	Record Observations	Pencil, Paper, Tape Recorder.	8			19-C	1/10 Days	0	1	76	5 Yrs	
(9)	Turn Off Instrumentation	Test/Monitoring Console.	5			19-C	1/10 Days	0	1	76	5 Yrs	
(10)	Reconfigure Habitability Areas As Required.	Hand Tool Kit Plan & Bldg Matls	4		X	22-A	1/90 Days	4 Hrs	1	76	5 Yrs	
(11)	Troubleshoot and Repair Experimental Equipment	Test Equipment & Prints (Plans)	4		X	19-B	As Needed	30 Min	1	76	5 Yrs	
(12)	Perform Maintenance (Clean, Adjust, Replace Components)	Maintenance Kit	4		X	19-B	As Needed	0	1	76	5 Yrs	
(13)	Initiate Data Recording and Data Storage.	Test/Recording Console	8		X	19-C	1/90 Days	Concurrent with Experiment.	1	76	5 Yrs	
(14)	Evaluate Data Acquisition	———	6		X	19-C	1/90 Days	10 Min	1	76	5 Yrs	
(15)	Correct for Bad Data.	———	8		X	19-B	———	10 Min	1	76	5 Yrs	
(16)	Initiate Transmission to Ground.	———	9			17-B	Daily	1	1	76	5 Yrs	
(17)	Perform Habitability Experiment Tasks.	Experiment Plan.	5		X	21-A	Continuous.	Continuous.	1-3	76	5 Yrs	
(18)	Record Subjective Comments	Tape Recorder	8		X	19-B	1/10 Days	1	1	76	5 Yrs	

RESEARCH CLUSTER
NO. 1-MM-4

CREW ACTIVITY MATRIX

RESEARCH CLUSTER NO.	TASK DESCRIPTION	EXPERIMENT EQUIPMENT	TYPE OF ACTIVITY	PECULIAR ENVIRONMENTAL REQUIREMENTS	EXCLUSIVE	CREW SKILL	FREQUENCY	TASK TIME (MIN)	NO. OF CREWMEN	START	DURATION	TASK CONCURRENCY
1-MM-4 (1)	Prepare Experiment Area for Work, Rest, Sleep Cycle Experiment.	Experiment Plan.	3		X	19-C	8/Crewman /90 Days	0	1	77	5 Yrs.	
(2)	Checkout Monitoring, Test, and Recording Equipment.	On-Board Recording & Checkout Equip.	3		X	19-C	" " " "	30 Sec	1	77	5 Yrs.	
(3)	Retrieve and Review Experiment Plan.	————	3		X	19-C	" " " "	30 Sec	1	77	5 Yrs.	
(4)	Brief Experiment Subjects	Instruction Material	5		X	21-A	" " " "	30 Sec	1	77	5 Yrs.	
(5)	Turn On Instrumentation	Test Monitoring Console, EEG, Tape Recorder, TV Recording	5		X	19-C	Once per Day	1 Sec	1	77	5 Yrs.	
(6)	Observe Conduct of Experiment	————	5		X	19-A	Once per Day	15	1	77	5 Yrs.	
(7)	Evaluate Observations	————	8		X	19-A	Once per Day	0	1	77	5 Yrs.	
(8)	Record Observations	Pencil, Paper, Take Recorder.	8		X	19-C	Once per Day	0	1	77	5 Yrs.	
(9)	Turn Off Instrumentation	Test/Monitoring Console.	5		X	19-C	Once per Day	0	1	77	5 Yrs.	
(10)	Reconfigure Work/Rest/Sleep Experiment Areas As Required.	Hand Tool Kit Plans & Bldg Mtls	4		X	22-b	As Needed	30 Min	2	77	5 Yrs.	
(11)	Troubleshoot and Repair Experimental Equipment.	Test Equipment & Prints (Plans)	4		X	19-B	Once As Needed	30 Min	1	77	5 Yrs.	
(12)	Perform Maintenance (Clean, Adjust, Replace Components).	Maintenance Kit.	4		X	19-B	Once As Needed		1	77	5 Yrs.	
(13)	Initiate Data Recording and Data Storage	Test/Recording Console.	8		X	19-C	Once per Day	Concurrent W/Expermt.	1	77	5 Yrs.	
(14)	Evaluate Data Acquisition.	————	6		X	19-C	Once per Day	10	1	77	5 Yrs.	
(15)	Correct For Bad Data.	————	8		X	19-B	Once per Day	10	1	77	5 Yrs.	
(16)	Initiate Transmission to Ground.	————	9		X	17-B	Twice per 90 Days	1	1	77	5 Yrs.	
(17)	Perform Work, Rest, Sleep Cycle Experiment.	Experiment Plan.	5		X	21-A	4 times early in mission & 4 times late in mission	15 Min. Per Session, 8/Man.	3	77	5 Yrs.	
(18)	Record Subjective Comments	Tape Recorder	8		X	19-B	Once Per Experiment	15 Mins.	1	77	5 Yrs.	

CREW ACTIVITY MATRIX

RESEARCH CLUSTER NO.		TASK DESCRIPTION	EXPERIMENT EQUIPMENT	TYPE OF ACTIVITY	PECULIAR ENVIRONMENTAL REQUIREMENTS	EXCLUSIVE	CREW SKILL	FREQUENCY	TASK TIME (MIN)	NO. OF CREWMEN	START	DURATION	TASK CONCURRENCY
1-MM-5	1)	Set up task board for tool or remote manipulator experiment and prepare for experimental run	task board and attached instrumentation, tools and spares. remote manipulator	3	None	X	5c	3/wk 1/wk	15	1	'74 '76	3 5	3
	2)	Set up TV camera and lights for tool and remote manipulator experiments	light meter TV monitor	3	None	X	20c	3/wk 1/wk	15	1	'74 '76	3 5	3
	3)	Prepare for experimental run on tool and remote manipulator experiments (don instrumentation, pressure suits)	heart rate electrodes, pressure suit and connections	1	None	X	0–C	2/wk 1/9 days	15	1	'74 '76	3 5	1 & 2
	4)	Perform experimental tool and remote manipulator tasks		1	None	X	0–C	3/wk 1/wk	30	1	'74 '76	3 5	6
	5)	Doff pressure suits at end of tool and remote manipulator experiment task		1	None	X	0–C	2/wk 1/9 days	10	1	'74 '76	3 5	
	6)	Initiate, monitor and terminate tool and remote manipulator experiment	TV monitor and video recorder timers, experimenter's console	5	None	X	5b	3/wk 1/wk	30	1	'74 '76	3 5	4
	7)	Set up experimental devices and measurement equipment for optical aids experiments	tracking device data recorders	3	None	X	19c	2/wk	10	1	'75	2	
	8)	Perform optical aids experimental task	optical aids tracking device	1	None	X	0–C	2/wk	15	1	'75	2	9 & 10
	9)	Initiate, monitor, and terminate optical aids experiment task	displays intercom	5	None	X	0–C	2/wk	15	1	'75	2	8 & 10
	10)	Control spacecraft to establish and maintain required attitude and track for optical aids experiment	S/C controls and displays, intercom	2	None		21a	2/wk	20	1	'75	2	8 & 9
	11)	Set up job aids preparatory to initiation of job aids experimental task	job aids at operational work station	3	None	X	5c	3/wk	10	1	'74	2	
	12)	Perform job aids experimental task (operational task with experimental job aids)	" "	1	None	X	22b	3/wk	30*	1	'74	2	
		*Time not chargeable to this experiment but to the operational, support or experimental function under which the task is performed.											
	13)	Initiate, monitor, and terminate job aids experimental task	timers, TV cameras, recorders	5	None	X	5c	3/wk	30	1	'74	2	
	14)	Remove and stow job aids		3	None	X	5e	3/wk	5	1	'74	2	
	15)	Enter subjective comments in crew log	tape recorder	8	None	X	0–C	6/wk 1/wk	5	1	'74 '76	3 5	

EARTH ORBITAL EXPERIMENT PROGRAM
AND REQUIREMENTS STUDY

MANNED SPACEFLIGHT CAPABILITY

RESEARCH CLUSTER—1-LS-1
PHASE CHANGE AND THERMAL PROCESSES

C-1-193

RESEARCH CLUSTER SYNOPSIS—MANNED SPACEFLIGHT CAPABILITY
1-LS-1
Phase Change and Thermal Processes

1. Research Objectives

The objective of the research cluster on phase change and thermal processes is to provide the basic knowledge necessary to design and qualify efficient and practical life support equipment that relies on boiling heat transfer as an integral process. The research results will take the form of heat fluxes versus heating element temperature at varying pressures and accelerations. Additionally, movie film records will provide data on bubble generation, breakoff, and motion which is essential to the satisfactory solution of phase separation problems in very low-g equipment.

This research cluster relates to the broad objectives for development of technology for highly reliable systems to support and protect man and enhance his capability to perform spaceflight operations. The research is particularly applicable for developing life-support systems for long-duration missions which are essential to lower-cost centralized Earth-orbiting bases, long-duration specialized stations, and lunar and planetary exploration vehicles. The phase change and thermal processes research group is inherent to 23 critical issues included under the headings of atmosphere supply, carbon dioxide control, thermal control, water storage/preservation, and water reclamation.

2. Background and Current Status

Realization of NASA long-term goals of low-cost, long-term exploration relies heavily upon EC/LS designs, wherein nearly all the crew waste products are converted to useful commodities in the spacecraft. Many of the candidate approaches rely on boiling heat transfer for converting liquid to gas as a necessary step of the process. For example, use of subcritical cryogenic atmosphere storage requires a phase change of the liquid to a gas in a heat exchanger by boiling heat transfer. The solid amine CO_2 control concept consists of absorption beds which are regenerated by steam produced by boiling heat transfer in a steam generator.

Currently, there is insufficient empirical data to confidently design efficient zero-g hardware for these applications. Theory is available to analytically predict performance of these devices but this theory must be complemented by empirical test results.

Essentially all available data on boiling heat transfer is applicable to Earthbound, 1 "G" environment. This data is of little value for space design of equipment because of the invalidity of extrapolation to very low acceleration levels.

3. Description of Research

Incipient and nucleate boiling is studied in this research group by heating typical surfaces (horizontal plate, vertical plate, sphere and cylinder) in a liquid tank subject to a steady low gravity force by varying orientations, heat flux rates, and pressures. Parameters to be measured include heat flux, temperature, pressure, bubble size, growth rate, bubble velocity, g force, g-force direction. The parameters associated with bubble behavior are measured with a high-speed movie camera. Parameters of heat flux, temperature and pressure are measured with conventional laboratory techniques.

The experiment apparatus consists of a cylindrical plexiglass tank with viewports for cameras, TV, lighting and viewing. A spring-held porous membrane is located at one end of the tank to retain liquid and separate ullage. The sample surfaces are heated by buried nichrome heaters. Electrical power to the heaters is varied over the entire range of characteristic boiling from incipient to nucleat boiling. The temperature difference between the sample surface and the saturated liquid is recorded at regular intervals. This data provides the basis for classical pool boiling curves which are repeated at different gravity levels. A number of geometric surfaces are used in the test such as cylindrical, spherical and flatplate.

Crew involvement during initial setup consists of installing test surface, filling tank, adjusting lights, focusing camera, and calibrating instrumentation. During the test run the crew monitors instrumentation and controls power to the heating element. The crew shuts down the equipment by deactivating power sources, emptying the tank and removing the test surface. This experiment may also be performed in an unmanned experimental module with input-output data linked to the space research facility.

Three experiments within this research cluster were identified and described in detail under NASA contract NAS1-9248 "Requirements Study for a Biotechnology Laboratory for Manned Earth Orbiting Missions." These were designated in that study as

4-101	Nucleate boiling
4-103	Convection heat transfer
4-106	Diffusion convection

and are described briefly in Appendix H of this report.

4. Impact on Spacecraft

The research cluster requires crew time for setup and running the tests by a crewman having a knowledge of boiling phenomenon. This knowledge is particularly important to prevent runaway burnout conditions are encountered in film boiling where the heating rate becomes excessive.

Electrical power is consumed by the experiment in amounts up to 1,500 watts, but averaging about 200 watts. The peak power requirements are not expected to exceed 10 percent of the total run time.

The fixed weight estimate for the test apparatus is 300 lb and resupply is required for film, recording tape and test surfaces. These will be returned by logistics after the data has been recorded.

Gas and liquid interfaces exist from the spacecraft to provide gas for pressurizing the experiment and water for charging the cylindrical tank. Upon completion of testing, the tank is drained with the water returning to the Space Station water management system for processing.

Low gravity is produced for the Phase Change and Thermal Processes research cluster by use of the spacecraft propulsion system. Scheduling of the experiment must be done to prevent interference with other experiments requiring zero-g. If the experiment can be scheduled during routine use of thrustors, propellant requirements can be minimized.

Portions of the onboard data management system may be useful for data processing of experiment results. An initial screening of data before returning it to Earth enables the tests to be rescheduled immediately and ensures Earth return of valid data.

5. Required Supporting Technology Development
The research testing techniques must be verified by ground testing prior to implementation of the space research program. Operation of certain elements of the test apparatus are space independent and these include the bulk instrumentation and supporting equipment. Test runs performed with the equipment in the final space apparatus configuration will ensure adequacy and validity of test sequences and data acquisition.

Peripheral equipment and procedures for the purpose of data reduction, correlation and interpretation must be developed prior to the space test program to ensure that valid data is promptly available in a useful form for design of future space equipment.

6. References

1. H. Schlichting. Boundry Layer Theory. McGraw-Hill, Inc. 1960.

2. R.S. Osborne, et al. The Needs and Requirements for a Manned Space Station. Research and Development in Advanced Technology. NASA, November 1966.

3. C.H. Gibson, C.C. Chen, and S.C. Lin. Measurements of Turbulent Velocity and Temperature Fluctuations in the Wake of Sphere. Journal of AIAA, Vol. 6, No. 4. April 1968, p. 642.

4. L.M. Swain. On the Turbulent Wake Behind a Body in Revolution. Proceedings of the Royal Society of London, Series A, Vol. 125, 1929.

5. L.D. Landau and E.M. Lifshitz. Fluid Mechanics. Addison Wesley, 1959.

6. T.A. Harmathy. Velocity of Large Drops and Bubbles in Media of Infinite or Restricted Extent. Journal of the American Institute of Chemical Engineers, Vol. 6, No. 2, June 1960.

Critical Issues Addressed by Research Cluster

1-LS-1

PHASE CHANGE AND THERMAL PROCESSES

1.1.3.1.1.1.1.3
Under space flight conditions what heat transfer problems in thermal decomposition of chemicals require investigation?

1.1.3.1.1.1.3.1
What thermodynamic processes are involved in the delivery of cryogenically stored oxygen and nitrogen in a space environment?

1.1.3.1.1.1.3.5
What are the density profile characteristics of liquids at and near the critical state?

1.1.3.1.1.1.3.6
How can gas-free cryogenic liquid transfer and maintenance be achieved in zero-g conditions?

1.1.3.1.1.2.1.1.2
What are the zero-g heat transfer problems involved in the operation of the solid electrolyte reactor?

1.1.3.1.1.2.1.1.6
How does zero-g affect the presence of water vapor in the CO_2 stream on the solid electrolyte reaction?

1.1.3.1.1.2.1.2.4
How does the presence of water vapor in the CO_2 stream affect the molten carbonate reaction in a weightless environment?

1.1.3.1.1.2.2.2.1.2
What are the gas-liquid interface problems in liquid/membrane electrolysis units caused by zero-g?

1.1.3.1.1.2.2.2.1.4
What are the zero-g effects of gas bubbles in the water electrolysis process?

1.1.3.2.1.4.3.2
How does weightlessness affect the heat transfer conditions involved in the molecular sieve CO_2 collectors?

1.1.3.2.1.4.4.3
How does zero-g influence the interface problems and devices involved in liquid absorption CO_2 collectors?

1.1.3.2.1.4.4.5
What are the zero-g absorption characteristics of gases by liquids and how do they affect the liquid absorption CO_2 collector?

1.1.3.3.1.1.2.1
What are the effects of a space environment on the diffusion convection processes occurring in conjunction with ablative insulation subsystems?

1.1.3.3.2.1.1.1.5
What are the effects of a space environment on phase-change substances used in heat storage systems?

1.1.3.3.2.2.2.2.1
How does zero-g affect condensing heat transfer?

1.1.3.4.2.2.1.1
What are the zero-g boiling heat transfer problems in the air evaporation process?

1.1.3.4.2.2.3.1
What are the effects of zero-g on heat transport in the vapor diffusion compression process?

1.1.3.4.2.2.4.1
What are the space effects on heat transfer problems in the vapor pyrolysis process?

1.1.3.4.2.2.5.1
How does zero-g affect the vapor compression process?

1.1.3.5.2.3
What are the influences of zero-g on the heat transfer phenomena involved in the burning processes in waste management incineration?

1.1.3.5.3.1.4
What are the zero-g effects on mass and heat transfer involved in urine storage?

1.1.3.5.3.2.1
What are the space effects on fluid flow in conjunction with drying and/or mixing in feces and refuse storage systems?

EARTH ORBITAL EXPERIMENT PROGRAM
AND REQUIREMENTS STUDY

MANNED SPACEFLIGHT CAPABILITY

RESEARCH CLUSTER—1-LS-2
MATERIAL TRANSPORT PROCESSES

C-1-199

RESEARCH CLUSTER SYNOPSIS—MANNED SPACEFLIGHT CAPABILITY
1-LS-2
Material Transport Processes

1. Research Objectives

The research cluster on Material Transport Processes has as its objective the acquisition of data required to qualify life support equipment involving condensing heat transfer and fluid dynamics in null gravity. Information acquired by this research cluster is in the categories of local and mean condensing heat transfer coefficients, pressure drops, flow instability, and vapor liquid flow distribution. This information will be useful in the design of condensers, gas-liquid separators and fluid transfer devices and other equipment involving material transport.

This research cluster relates to the broad objectives for development of technology for highly-reliable systems to support and protect man and enhance his capability to perform spaceflight operations. The research is particularly applicable for developing life-support systems for long-duration missions which are essential to lower-cost centralized Earth orbiting bases, long-duration specialized stations and lunar and planetary exploration vehicles. The material transport processes group is inherent to fifty critical issues included under the heading of oxygen and diluent supply, atmosphere purification and control, thermal control, water management, and food chemical synthesis.

2. Background and Current Status

Life support equipment design for long-term manned spaceflight relies heavily upon the material transport processes and, as such, must be fully understood before flight-qualified hardware can be built. Advanced life support concepts, which are necessary for realization of NASA long-term goals of inexpensive long-term exploration, involve material transport processes to a large extent. For example, the candidate CO_2 remover, steam desorbed resin, relies on hot steam to desorb the beds and in order to design a null-gravity condenser-separator, empirical data is needed to supplement theory. Currently, there is insufficient basic data at low-g levels to allow a rigorous design. Theory is available which was derived primarily for normal Earth surface gravity, and although this may be adequate for very low-g levels, empirical data is necessary to verify the theory. Upon comparison of theoretical projections and the research cluster results, it may be necessary to modify existing theory or develop new theory for low-g or zero g application.

3. Description of Research

The experiment consists of passing a condensable fluid heated to the gas phase through glass tubes whose walls are kept at a temperature low enough to produce condensation. The study will evaluate the local and mean condensing heat transfer coefficients, pressure drops, flow instability and vapor liquid flow distribution. Parameters to be measured include fluid and wall temperatures, fluid pressures, flow rates, heater power, cooling fluid flow, temperature, g-level and time. Film recordings are made of the condensing phenomenon and the flow characteristics of two-phase flow.

All sensed data goes to a display panel where the crewman observes, adjusts and controls flows, heat rates, pressure, camera and TV position, focus and lighting. Recorder provides continuous tape of sensor data. Camera records on film and may be processed by dry-pack for space study.

The research equipment consists of a boiler for heating the test fluid, a tubular condenser section for test and observation of condensing phenomenon, and a coolant loop for cooling the condenser tubes below the condensing temperature. Various support equipment is provided such as pumps, valves, and flow meters to control the fluid loops. Sensing instrumentation includes thermocouples, pressure sensors, flow meters, and a volt/ammeter for power. A television camera provides viewing capability from remote and a high-speed camera records condensing phenomenon.

The test fluid is heated to a vapor in the boiler and then passed to the condenser section where the test fluid is condensed on the tube surfaces. By measuring the tube and fluid temperatures and pressures the condensing coefficients can be determined. The measurement of fluid and vapor flow requires a suitable technique for their separation in zero g. This experiment is repeated for various levels of vehicle acceleration. As the fluid is withdrawn from the tubes, data is obtained on flow instability and vapor liquid flow distribution. Camera records will be particularly useful for obtaining this data because it is largely visual.

The crew prepares for a test by bringing telemetering and data handling equipment on line, starting up instrumentation, lights, pumps, TV camera, and ensuring that the cooling loop is operating properly. During the test run the crewman adjusts boiler and condenser conditions to obtain and maintain the operation of those devices within operating limits and to obtain the desired characteristic phenomenon. Visual observations will be made of the condensing process and adjustments made to cameras and lights to obtain valid records. The crewman must adjust g-level by actuation of the reaction control system.

Upon completion of a test run, the data will be reviewed by the crewman to assess the validity of the run and to reschedule and modify the test procedure to obtain desired data.

This experiment may also be performed in an unmanned experimental module with input-output data linked with the space station.

Three experiments within this research cluster were identified and described in detail under NASA contract NAS1-9248 "Requirements Study for a Biotechnology Laboratory for Manned Earth Orbiting Missions." These were designated in that study as

4-102	Flow regime characteristics
4-107	Inertial separation
4-108	Film stability and transport

and are described briefly in Appendix H of this report.

4. Impact on Spacecraft

The operating crewman for this research cluster must have a knowledge of material transport processes and of the test apparatus and associated equipment. Knowledge of material transport processes are necessary for recognition of the various regimes and for apparatus adjustments required to obtain data for the desired regime.

The spacecraft subsystems are utilized for providing power, cooling and a portion of the data management requirement. Additionally, much experiment support hardware, such as cameras, instrumentation and displays is expected to be common among a number of experiments and is included as Space Station equipment.

Electrical power in amounts up to 1.5 Kw will be consumed by the experiment hardware. The bulk of this will be dc current for the boiler heater controls and valves with lesser amounts of ac used in pumps.

Condenser cooling may be supplied by a separate experiment expendable cooling system or by the onboard active thermal loop if a sufficiently low temperature is available. The advantage of utilizing the onboard thermal control is to reduce expendables and gain experiment schedule flexibility by eliminating use of cryogenic stores.

The fixed equipment weight estimated is 500 lb and requires an envelope of 5 ft by 2.5 ft by 2.5 ft. Logistics are required for resupplying film, estimated at 10 lb and cryogenics fluid, 45 lb, if the spacecraft thermal loop is not used.

The spacecraft reaction control system will be activated to produce the artificial-g levels required by the experiment. Propellant savings could be obtained if testing can be performed in conjunction with spacecraft needs.

Initial screening of data will be performed by the onboard spacecraft data management system. This will ensure returning to Earth of data of greater validity and enables immediate rescheduling of test reruns.

5. Required Supporting Technology Development
Prior to implementation into the space research program, the test concepts and equipment must be verified. Much of the test equipment is zero-g independent and these elements can be satisfactorily ground-tested to ensure proper operation. This applies particularly to instrumentation and other experiment support equipment. Ground testing will also verify test operation sequences and data acquisition techniques.

Peripheral equipment and procedures for the purpose of data reduction, correlation and interpretation must be developed prior to the space test program to ensure that the acquired data is valid and immediately available in useful form to designers of space life support equipment.

6. References

1. J. W. Miles. The Hydrodynamic Stability of a Thin Film. Journal of Fluid Mechanics. 8, 1960, p. 593.

2. F. W. Booth, Research on a Zero-Gravity Air Separator, NASA-LWP-458. Aug. 1967.

3. M. T. Lawler, et al. A Study of Cyclonic Two-Fluid Separation. AFOSR 65-1523. June 1965.

4. J.M. Smith, et al. The Application of Hydrophilic and Hydrophobic Surfaces for Phase Separation in a Low-G Environment. Paper 16, Symposium for Fluid Mechanics and Heat Transfer Under Low-Gravity. June 1965.

5. T.M. Olcott, et al. Evaluation Testing of Zero Gravity Humidity Control System. NASA-CR-66543. Oct. 1967.

6. V.N. Serebrayakov. Control of the Dynamics of a Two-Phase Liquid-Gas Weightless Medium with the Aid of Surface Effects. Kosmicheskiye Issledovaniya, Vol. 4, No. 5, 1966 (NASA TTF-469, May 1967).

7. S.I. Soo. Fluid Dynamics of Multiphase Systems. Blaisdell Publishing Company, Massachusetts, 1967.

8. J. Ballinger, et al. Study of Zero Gravity Capabilities of Life Support Systems Components. Final Report NAS1-6939, NASA-CR-66534, GDC-DBD 67-004. Feb. 1968.

9. S. Chandrasekhar. Hydrodynamic and Hydromagnetic Stability. Oxford Press, 1961.

10. R. Arnet, et al. A Theoretical Model for Predicting Thermal Stratification and Self-Pressurization of a Fluid Container. Conference on Propellant Tank Pressurization and Stratification. NASA-MSFC. January 1965.

11. D. Keating. Atmosphere Movement in Sealed Environments for Manned Space Mission. AMRL-WPAFB. Chemical Engineering Technical Note 02-02-03-279.

12. S. W. Gouse. An Introduction to Two-Phase Gas Liquid Flow. MIT Engineering Projects Laboratory Report 8734-3. June 1964.

13. H. Henry. Two-Phase Flow and Heat Transfer in Porous Beds Under Variable Body Forces. Contract NAS8-21143. University of Alabama, Sept. 1969.

14. E. Quandt. Analysis of Gas-Liquid Flow Patterns, Chemical Engineering Progress Symposium Series Vol. 61, (Heat Transfer). Boston, 1965, pp. 128-138.

Critical Issues Addressed by Research Cluster

1-LS-2

MATERIAL TRANSPORT PROCESSES

1.1.3.1.1.1.1.2
What mass transfer phenomena in the diffusion of products from sources and in separation processes occur under space flight conditions?

1.1.3.1.1.1.3.1
What thermodynamic processes are involved in the delivery of cryogenically stored oxygen and nitrogen in a space environment?

1.1.3.1.1.1.3.7
What zero-gravity interface phenomena of liquid-gas systems are involved in cryogenic storage of atmospheric gases?

1.1.3.1.1.1.3.8
What are the zero-g kinetic and dynamic characteristics of gas bubbles and how do they influence the operation of cryogenic stores?

1.1.3.1.1.1.3.10
What are the consequences of the vapor purge of cryogenic liquid systems in zero-g?

1.1.3.1.1.2.1.2.8
What are the zero-g operational effects on the gas-liquid-solid system involved in the molten carbonate reactor?

1.1.3.1.1.2.2.1.1.2
How does zero-g affect the gas-liquid separation characteristics of the effluents from the Sabatier reactor and condenser?

1.1.3.1.1.2.2.1.2.2
How does weightlessness influence the gas-liquid separation characteristics of the effluents from the Bosch reactor and condenser?

1.1.3.1.1.2.2.2.1.2
What are the gas-liquid interface problems in liquid/membrane electrolysis units caused by zero-g?

1.1.3.1.1.2.2.2.1.4
What are the zero-g effects of gas bubbles in the water electrolysis process?

1.1.3.2.1.4.1.2
What are the gas-liquid separation problems associated with the zero-g operation of the electrodialysis CO_2 collectors?

1.1.3.2.1.4.2.1
What are the zero-g mass transport characteristics of solid amines?

1.1.3.2.1.4.3.1
How does zero-g influence the mass transfer parameters involved in the molecular sieve CO_2 collectors?

1.1.3.2.1.4.4.3
How does zero-g influence the interface problems and devices involved in liquid absorption CO_2 collectors?

1.1.3.2.1.4.4.4
What are the mixing characteristics of liquids in zero-g and how do they affect the liquid absorption CO_2 collector?

1.1.3.2.3.3.2.2
How does zero-g affect gas liquid separation involved in humidity control subsystems?

1.1.3.3.1.1.1.2
How does zero-g affect the diffusion convection processes occurring in conjunction with entrapped gases in high vacuum insulation?

1.1.3.3.1.1.2.1
What are the effects of a space environment on the diffusion convection processes occurring in conjunction with ablative insulation subsystems?

1.1.3.3.1.3.2
What are the zero-g influences on mass transfer diffusion processes in heat pipes?

1.1.3.3.1.3.3
What are the zero-g effects on fluid flow characteristics, involved in capillary transport processes in heat pipes?

1.1.3.3.2.1.1.1.4
What are the effects of zero-g on liquid/solid/gas separation devices?

1.1.3.3.2.2.1.2.1.3
What are the effects of zero-g on liquid/gas separators used with condensing radiator systems?

1.1.3.3.2.2.2.2.2
What are the effects of a space environment on liquid/gas separation in condenser systems?

1.1.3.4.1.1.1
How does zero-g influence mass transfer in the diffusion of liquids and/or gases through the tank bladders?

1.1.3.4.1.1.2
How do zero-g conditions effect fluid flow characteristics of expulsion gas and water, involved in bladder tank storage?

1.1.3.4.1.2.2
How does zero-g influence fluid flow characteristics of chemical preservation method of water storage?

1.1.3.4.2.1.1
What are the zero-g affects on the flow regime characteristics in water filtration processes?

1.1.3.4.2.1.2
What are the effects of zero-g in gas/liquid separation problems in water filtration processes?

1.1.3.4.2.1.3
How does a zero-g environment influence the mixing characteristics of fluids in the filtration processes?

1.1.3.4.2.1.5
What are the effects of a space environment on the flow regime characteristics in the reverse osmosis process?

1.1.3.4.2.1.6
What are the zero-g effects on gas/liquid separation devices in the reverse osmosis process of reverse osmosis water recovery units?

1.1.3.4.2.1.7
How does zero-g affect the mixing characteristics of fluids in the reverse osmosis process?

1.1.3.4.2.2.1.2
How does zero-g affect the flow regime characteristics in the air evaporation process?

1.1.3.4.2.2.1.3
What are the effects of zero-g on the mixing characteristics of fluids used in the air evaporation process?

1.1.3.4.2.2.2.2
What are the zero-g effects on membrane diffusion used in conjunction with vapor diffusion process?

1.1.3.4.2.2.2.3
How does a space environment affect gas/liquid separation in the vapor diffusion process?

1.1.3.4.2.2.3.2
How does zero-g influence gas/liquid separation devices in the vapor diffusion compression process?

1.1.3.4.2.2.4.2
What are the zero-g effects on gas/liquid separation in the vapor pyrolysis process?

1.1.3.4.2.2.5.2
What are the zero-g effects on the flow regime in the vapor compression process?

1.1.3.4.2.2.5.3
What are the zero-g effects on the gas/liquid separation devices used in the compression process?

1.1.3.5.1.1.1
What are the zero-g phase separation and liquid fluid flow characteristics, involved in urine collection?

1.1.3.5.1.2.1
What are the zero-g flow characteristics involved in feces and refuse collection?

1.1.3.5.2.1
How does zero-g influence mass transfer in waste management incineration?

1.1.3.5.2.2
What are the zero-g fluid flow characteristics of combustion products and oxygen in the incineration waste management system?

1.1.3.5.3.1.3
What are the affects of space on the mixing characteristics used in conjunction with urine storage?

1.1.3.5.3.1.4
What are the zero-g effects on mass and heat transfer involved in urine storage?

1.1.3.5.3.2.2
What are the effects of zero-g on heat and mass transfer involved in drying and mixing processes on feces and refuse?

1.1.3.6.1.1.1
What are the effects of zero-g on mixing of solids and/or liquids in stored freeze-dried food management processes?

1.1.3.6.2.2.1
What are the effects of a space environment on gas/liquid separation involved in biological food regeneration process?

1.1.3.6.2.2.2
What are the zero-g effects on solid/liquid separation in processed biological food management?

EARTH ORBITAL EXPERIMENT PROGRAM
AND REQUIREMENTS STUDY

MANNED SPACEFLIGHT CAPABILITY

RESEARCH CLUSTER—1-LS-3
ATMOSPHERE SUPPLY PROCESSES

C-1-209

RESEARCH CLUSTER SYNOPSIS—MANNED SPACEFLIGHT CAPABILITY
1-LS-3
Atmosphere Supply Processes

1. Research Objectives

The research cluster on Atmosphere Supply Processes has the objective of evaluating optimum methods and systems dealing with supplying the spacecraft with the required atmospheric constituents from storage and processing systems. This objective will be realized through in-flight testing of several systems, integrated with the spacecraft life-support system, and operated for extended periods under conditions of zero gravity. The research in this experiment group is directed at 30 critical issues listed in Table 1; these issues were derived from an analysis of a NASA long-range objective in the Life Support and Protective Systems Program, which states the requirement ". . . to develop techniques and hardware for storing, dispensing, and conserving oxygen and diluent gases, and for regenerating oxygen and diluents." Detailed test data are needed to provide for the optimum design of systems for space with minimum maintenance and repair.

2. Background and Current Status

The NASA long-range objectives include ". . . the development of the technology for highly reliable systems to support and protect man and enhance his capability to perform space flight operations, and to provide efficient reclamation processes for life-sustaining oxygen regeneration." To reduce the resupply weight of expendables, it is necessary to close the loop by recovering as much of the oxygen from the CO_2 and water as possible. A number of recovery-system processes have been formulated, tested in the laboratory, or used in integrated manned life-support tests. These include the Sabatier and Bosch systems and components of the molten carbonate and solid electrolyte systems. NASA has sponsored research in the hardware development of the processes, and McDonnell Douglas has conducted extended manned tests of up to 90 days on the Sabatier unit in a Space Station Simulator. Ultimately, the processes must be subjected to long-duration tests in a space environment to insure that the many physical processes, such as liquid and vapor separation, heat transport, and mass transport takine place in the units will operate reliably, particularly in a zero-g environment.

Data obtained from such tests will permit the optimum design of equipment, providing maximum reliability, minimum power, and minimum maintenance and repair.

3. Description of Research

The experiment will consist of testing up to three or more units, each containing a complete atmospheric supply process. Carbon dioxide and (if necessary) hydrogen gas are fed to each unit, and the products of the reactions are collected, analyzed, and stored or directly returned to the unit. Each unit is provided with electric power, and heating and cooling loops, and has internal sensors for measurement of temperature, pressures, and power. The output information is recorded, displayed, and fed to a process-control unit, which automatically regulates the mass and energy flow for operation at desired conditions. Chemical analysis of the products is also to be accomplished automatically.

One experiment within this research cluster was identified and described in detail under NASA contract NAS1-9248 "Requirements Study for a Biotechnology Laboratory for Manned Earth Orbiting Missions." It was designated in that study as

4-104	Advanced fluid storage and management

and is described briefly in Appendix H of this report.

4. Impact on Spacecraft

Continued long-duration testing of the units will require an ample supply of CO_2 and H_2. The systems will be designed to supply the crew with approximately 2 lb of oxygen per man-day. The volume of the experiment is 24 ft^3 (2 by 3 by 4 ft), the total test system weight is 600 lb, and the power requirement is estimated at 1,000 w for a three-man system. The by-product gases must be either dumped overboard periodically or used in a biowaste electric propulsion system, but the by-product water may be made available for use in the baseline system. The by-product solids such as carbon, used catalyst, screens, and filters are stored for return to Earth.

The crew must have an engineering background and possess familiarity with life-support systems, operations, and test. A fully automated test experiment will require one man to start up and a monitor each unit, for approximately 2 hr, and 1 hr per day thereafter for monitoring of output data.

Each unit will be subjected to varying conditions of flow rates, heating, cooling, and pressures (subject to the discretion of the test conductor), and tested for up to one crew cycle.

5. Required Supporting Technology Development

The theory regarding the physical chemistry relating to the process involved in recovering O_2 for CO_2 is well understood. Additional research and technological advances, however, are required in the areas of materials, catalysts, zero-g condensation, boiling, and two-phase liquid/vapor separation, all of which are incorporated into the atmospheric supply process units and are common to the general cluster of life support and protective systems. The development of the theory confirmed by laboratory and single-component testing must precede the assembly of an integrated unit for space testing. Some of the recovery systems (e.g., Sabatier/Methane) will have reached a significant stage of development and test. Others, such as the Bosch process are in the experimental stage.

6. References

1. Proceedings of Winter Study on Users of Manned Space Flight, 1975-1985. Volume 2, NASA SP-196, NASA Science and Technology Advisory Committee for Manned Space Flight, La Jolla, California, December 6-9, 1968.

2. Aviation and Space, Progress and Prospects. ASME Annual Aviation and Space Conference, Beverly Hills, California, June 16-19, 1968.

3. Study of Life Support Systems for Space Missions Exceeding One Year in Duration, Phase 1A, Volume 1. NASA CR-73158, Lockheed Missiles and Space Company, Sunnyvale, California, December 15, 1967.

4. Life Support System for Space Flights of Extended Time Periods. NASA CR-614, General Dynamics, San Diego, California, November 1966.

5. Parametric Study of Manned Life Support Systems, Volume 2. NASA CR-73283 DAC-56713, McDonnell Douglas Astronautics Company, Western Division, January 1969.

Critical Issues Addressed by Research Cluster

1-LS-3

ATMOSPHERE SUPPLY PROCESSES

1.1.3.1.1.1.1.1
What are the operational aspects and/or interfaces of chlorate candles, ozonites and super-oxide, for the supply of nitrogen and hydrogen, and how are they affected by zero-g conditions?

1.1.3.1.1.1.1.4
What material types need to be investigated and/or developed in conjunction with chemical storage or atmospheric gases for spacecraft applications?

1.1.3.1.1.1.1.5
What are the basic physical processes involved in the chemical storage of atmospheric gases and how are they altered under zero-g conditions?

1.1.3.1.1.1.2.1
What are the operational problems of gaseous storage systems for the supply of oxygen, nitrogen and hydrogen, and what changes occur under zero-g conditions?

1.1.3.1.1.1.3.9
What are the effects of a space environment on integrated cryogenic storage subsystems?

1.1.3.1.1.2.1.1.1
What are the space effects on electrochemical reactions involved in the operation of the solid electrolyte reactor?

1.1.3.1.1.2.1.1.3
What are the zero-g effects of the carbon accumulation problem on the operation of the solid electrolyte cell?

1.1.3.1.1.2.1.1.4
How will zero-g affect the materials used for solid electrolyte cell electrodes?

1.1.3.1.1.2.1.1.5
How does zero-g affect solid electrolyte components?

1.1.3.1.1.2.1.2.1
How are the electrochemical reactions of the molten carbonate reactor system affected in the space environment?

1.1.3.1.1.2.1.2.3
How does weightlessness affect the carbon accumulation and the operation of the molten carbonate reactor?

1\. 1. 3. 1. 1. 2. 1. 2. 5
How does zero-g affect the materials used for the molten carbonate cells?

1\. 1. 3. 1. 1. 2. 1. 2. 6
What electrolyte is most suitable for the operation of molten carbonate reaction in a space environment?

1\. 1. 3. 1. 1. 2. 1. 2. 7
What are the handling problems involved with the carbonate melt in a weightless environment?

1\. 1. 3. 1. 1. 2. 1. 2. 9
How does a space environment affect the molten carbonate components?

1\. 1. 3. 1. 1. 2. 2. 1. 1. 3
How does a space environment affect the mechanisms involved in the Sabatier reaction?

1\. 1. 3. 1. 1. 2. 2. 1. 1. 4
How does zero-g influence the partial cracking of methane?

1\. 1. 3. 1. 1. 2. 2. 1. 1. 5
How does zero-g influence the full cracking of methane?

1\. 1. 3. 1. 1. 2. 2. 1. 1. 6
How does a space environment affect the operation of Sabatier components?

1\. 1. 3. 1. 1. 2. 2. 1. 2. 3
What are the zero-g effects of the carbon accumulation on the operation of the Bosch reactor?

1\. 1. 3. 1. 1. 2. 2. 1. 2. 4
What are the effects of zero-g on characteristics and mechanisms involved in the Bosch reaction?

1\. 1. 3. 1. 1. 2. 2. 1. 2. 5
How does a space environment affect the operation of the Bosch components?

1\. 1. 3. 1. 2. 2. 1
How will zero-g affect dual gas atmosphere pressure control when using polarographic sensors?

1\. 1. 3. 1. 2. 2. 2
How will zero-g affect dual-gas atmosphere pressure control when using paramagnetic sensors?

1.1.3.1.2.2.3
How does zero-g affect dual-gas atmosphere pressure control when using mass spectrometers?

1.1.3.1.2.2.4
How does zero-g affect dual-gas atmosphere pressure control when using gas chromatographs?

1.1.3.5.3.1.1
What are the effects of zero-g on the basic processes involved in urine storage in waste management systems?

1.1.3.8.3
What are the space effects on an integrated animal EC/LS?

1.1.3.8.4
What are the space effects on the integrated EC/LS and power?

1.1.3.8.5
How does space affect an integrated life support system?

EARTH ORBITAL EXPERIMENT PROGRAM AND REQUIREMENTS STUDY

MANNED SPACEFLIGHT CAPABILITY

RESEARCH CLUSTER—1-LS-4
WATER MANAGEMENT

2-1-215

RESEARCH CLUSTER SYNOPSIS—LIFE SUPPORT AND PROTECTIVE SYSTEMS
1-LS-4
Water Management

1. Research Objectives
The Water Management Experiment Group has the objectives of evaluating the techniques and hardware for optimum storage and preservation of water; and the reclamation of water from bio-wastes, including urine, condensate, and wash water. These objectives will be realized by testing various hardware sub-systems in a space environment under spaceflight conditions.

The research in this experiment group (categorized under the heading Water Management) is addressed to 25 critical issues, which were derived from a detailed analysis of a NASA long-range objective in the Life Support and Protective Systems Program. This objective is "... to develop techniques and hardware for the reclamation and sterilization of potable water from waste water such as urine, wash water, and humidity condensate..."

Detailed test data for a variety of processing equipment, automatic control instrumentation, maintenance and repair procedures, and performance evaluation are needed to design optimum systems.

2. Background and Current Status
As stated in the NASA long-range objectives, the resupply of expendables for long-duration missions will not be practical. Consequently, the efficient regeneration and reclamation of wastes will provide potable water, and the involved regeneration processes for atmosphere and water will be utilized in solving pollution problems on Earth.

Water Management is concerned both with the storage and preservation of water, and with processes for reclamation from the wastes, including, among other techniques, membrane-filtration, and phase change processes.

Techniques for the storage and preservation of water include chemical treatment, or pasteurization. Treatment with such chemicals as chlorine and iodine has been shown to be effective biologically, but it produces an objectionable taste.

The use of silver ions has also been demonstrated; however, some problems have been encountered when used with anything but extremely pure water. The simplest and most reliable method used in long-term manned testing has been that of maintaining potable water at 160° F.

A number of processes for recovering potable water are currently under development. Air evaporation systems of completely zero gravity design have been successfully tested under conditions of human consumption in long-term simulator runs. Other methods that promise lower expendable penalties for long-term missions are under development. A zero-gravity design vapor pyrolysis system has been demonstrated. The vacuum-distillation-vapor filtration, although currently incapable of operation in zero gravity, has recently undergone manned testing in a space station simulator. Other methods, such as vapor compression and electrochemical/electrodialysis, are currently approaching operational prototype status.

Successful long-term recovery of wash water has been demonstrated in space station simulator testing of a multifiltration process. The reverse osmosis process promises the reduction of expendable filters, although a membrane with a long useful life in the presence of organics has yet to be developed.

3. Description of Research

The proposed experiment will test several pilot water management systems and hardware components, using the wastes diverted from the baseline system. The recovered water will be stored in various trial storage systems and tested periodically. Parameters to be measured include temperatures, pressures, liquid and gas flow rates, heating and cooling requirements, chemical analysis of water and gases, microbial tests, hardware maintenance and repair, system adjustments, and finally crew evaluation of the water. It is anticipated that the systems will be automated for control and regulation as well as for most sample test analyses.

The crew will be required to bring the water recovery and storage systems to be tested to operational status, monitor the sensor outputs, perform minor adjustments, and maintain the equipment.

The data will be both displayed and taped for subsequent analysis.

One experiment within this research cluster was identified and described in detail under NASA contract NAS1-9248, "Requirements Study for a Biotechnology Laboratory for Manned Earth-Orbiting Missions." It was designated in that study as 4-114 Reverse-Osmosis Water-Recovery System and is described briefly in Appendix H of this report.

4. Impact on Spacecraft

The impact on the space station will be evidenced in a drain of power, and thermal-source and sink-flow loops if the experimental equipment demands are higher than the baseline system requirements. The equipment and materials for the Water Management Experiment are estimated to weigh 400 lb, occupy a volume of 20 ft^3, and require approximately 700 w of electrical power for supporting a three-man crew.

The crew will have to include an engineer who is familiar with the Water Management Experiment hardware. Once the system is in steady state operation, less than 10 percent of his time will be required for monitoring and maintenance.

5. Required Supporting Technology Development
Supporting research and technology will be required in the basic understanding of mass handling, phase change, and gas/liquid/solid separation in zero-g, since these processes are common to the design of virtually all of the water management systems.

In addition, the development of a flight-weight water-potability analyzer is necessary to reduce system complexity and weight.

6. References

1. Proceedings of Winter Study on Uses of Manned Space Flight, 1975-1985. NASA Science and Technology Advisory Committee for Manned Space Flight, Volume 2, NASA SP-196. La Jolla, California, December 6-9, 1968.

2. Aviation and Space, Progress and Prospects. ASME Annual Aviation and Space Conference, Beverly Hills, California, June 16-19, 1968.

3. Study of Life Support Systems for Space Missions Exceeding One Year in Duration, Phase 1A, Volume 1, NASA CR-73158. Lockheed Missiles and Space Company, Sunnyvale, California, December 15, 1967.

4. Life Support System for Space Flights of Extended Time Periods, NASA CR-614. General Dynamics, San Diego, California, November, 1966.

5. Parametric Study of Manned Life Support Systems, Volume 2, NASA CR 73283, DAC-56713. McDonnell Douglas Astronautics Company, Western Division, January 1969.

Critical Issues Addressed by Research Cluster

1-LS-4

WASTE MANAGEMENT

1.1.3.4.1.1.1
How does zero-g influence mass transfer in the diffusion of liquids and/or gases through the tank bladders?

1.1.3.4.1.1.2
How do zero-g conditions affect fluid flow characteristics of expulsion gas and water, involved in bladder tank storage?

1.1.3.4.1.2.1
What are the effects of zero-g on mass transfer involved in dissolution, mixing, plating out, and decomposition processes occurring in chemical preservation of water?

1.1.3.4.1.3.1
What are the effects of zero-g on the modes of heat transfer involved in maintaining the water temperature (between 100° and 160°F) with the pasteurization process?

1.1.3.4.2.1.1
What are the zero-g effects on the flow regime characteristics in water filtration processes?

1.1.3.4.2.1.4
How does zero-g affect the filtration process components and/or subsystems?

1.1.3.4.2.1.8
How does zero-g influence the design of reverse osmosis components?

1.1.3.4.2.2.1.1
What are the zero-g boiling heat transfer problems in the air evaporation process?

1.1.3.4.2.2.1.4
What are the zero-g effects on the gas/liquid separation devices used in the air evaporation process?

1.1.3.4.2.2.1.5
How does zero-g affect air evaporation components?

1.1.3.4.2.2.1.6
What are the space effects on an integrated air evaporation system?

1.1.3.4.2.2.2.1
What are the zero-g heat transfer effects involved in a vapor diffusion process?

1.1.3.4.2.2.2.4
What are the space effects on the operation of the vapor diffusion unit?

1.1.3.4.2.2.3.1
What are the effects of zero-g on heat transport in the vapor diffusion compression process?

1.1.3.4.2.2.3.3
What are the zero-g effects on vapor diffusion compression components?

1.1.3.4.2.2.3.4
What are the zero-g influences on the operation of the integrated vapor diffusion compression water recovery system?

1.1.3.4.2.2.4.1
What are the space effects on heat transfer problems in the vapor pyrolysis process?

1.1.3.4.2.2.4.3
What are the effects of zero-g on vapor pyrolysis components?

1.1.3.4.2.2.4.4
How does zero-g influence the design of the integrated vapor pyrolysis water recovery system?

1.1.3.4.2.2.5.1
How does zero-g affect vapor compression process?

1.1.3.4.2.2.5.4
What is the effect of zero-g on the vapor compression components?

1.1.3.4.2.2.5.5
What are the effects of space on the performance of the integrated vapor compression system?

1.1.3.8.3
What are the space effects on an integrated animal EC/LS?

1.1.3.8.4
What are the space effects on the integrated EC/LS and power?

1.1.3.8.5
How does space affect an integrated life support system?

EARTH ORBITAL EXPERIMENT PROGRAM
AND REQUIREMENTS STUDY

MANNED SPACEFLIGHT CAPABILITY

RESEARCH CLUSTER—1-LS-5
WATER ELECTROLYSIS

C-1-220

RESEARCH CLUSTER
NO. 1-LS-5

RESEARCH CLUSTER SYNOPSIS—LIFE SUPPORT AND PROTECTIVE SYSTEMS
1-LS-5
Water Electrolysis

1. Research Objectives

The Water Electrolysis Experiment Group has as its objectives the testing and design evaluation of advanced systems proposed for the electrolysis of water. These objectives will be realized by the in-flight testing of several systems integrated with the life support system and operated for extended periods under conditions of low or zero gravity. The research in this area is directed at eight critical issues, which were derived from a detailed analysis of the NASA long-range objective in the Life Support and Protective Systems Program, which is "...to develop techniques and hardware for regenerating oxygen and diluents..." Detailed test data are needed to select, and provide for, the optimum design of systems best suited for space operation and requiring minimum maintenance and repair.

2. Background and Current Status

The NASA long-range objectives include "...the development of the technology for highly reliable systems to support and protect man...and to provide efficient reclamation processes for life-sustaining oxygen regeneration." To reduce expendable resupply weight, it is necessary to recover as much oxygen as practical from the CO_2 and the electrolysis of water. Both the theory and processes for the operation of water electrolysis are well known; submarines have long used such systems for the production of oxygen from water; and several processes are under development by NASA, including (1) the asbestos-matrix potassium hydroxide (KOH) vapor feed system tested in the Langley Integrated Life Support System (ILSS), the 90-day McDonnell Douglas space simulator and the Space Station Prototype (SSP); (2) the sulfuric acid/water vapor cell developed by Ames Research Center, which operates by extracting the humidity directly from the cabin atmosphere; (3) an absorbent matrix KOH prototype which has been tested; and (4) a solid polymer electrolysis cell module under development by Langley Research Center. Only part of these systems, however, have been designed for zero-g although some zero-g designs have been bench-tested.

Further developments of the electrolysis systems for space applications include investigation of processes for the two-phase separation of gases from liquids, the prevention of cross diffusion of the gaseous oxygen and hydrogen, the extension of cell material life, and the maintenance of effluent gas purity.

3. Description of Research

The proposed experiment will consist of the testing of three or more advance water electrolysis systems, each sized for a one-man capacity. The units will be essentially closed systems, virtually automatic in operation, parameter sensing, and self regulation. Test parameters to be monitored include power consumption, water use rate, heat rejection rate, gas production rate, gas composition, temperatures and pressures. The monitored data will be both visually displayed and recorded on tape for subsequent analysis. The oxygen generated after collection and test will be added to the baseline system.

One experiment within this research cluster was identified and described in detail under NASA contract NAS1-9248, "Requirements Study for a Biotechnology Laboratory for Manned Earth Orbiting Missions." It was designated in that study as 4-105 Water Electrolysis System and is described briefly in Appendix H of this report.

4. Impact on Spacecraft

The test facility will occupy approximately 48 ft^3, weigh 450 lb and use a maximum of 700 w of electrical power for a three-man crew. A thermal load of 300 w is rejected to the spacecraft thermal control system. Approximately 60 channels of data will be generated. The experiment will generate breathing oxygen for three men and a comparable amount of hydrogen from the water electrolysis while utilizing 20 lb of water. The evolved hydrogen will be collected, stored, and added to the baseline waste-collection system.

5. Required Supporting Technology Development

Supporting research and technology is required in the areas of two-phase flow separation and condensation in zero-g, improved electrode and separator life, improved methods for separating the evolved oxygen and hydrogen gases, and method for identifying trace contaminants in effluent gases.

6. References

1. Aviation and Space Progress and Prospects. ASME, Annual Aviation and Space Conference, Beverly Hills, California, June 16-19, 1968.

2. Skylab-B Regenerative Life-Support System, MDAC G0442. McDonnell Douglas Astronautics Company—Western Division, July 1970.

3. Trade-Off Study and Conceptual Designs of Regenerative Advanced Integrated Life Support Systems (AILSS), NASA CR-1458. United Aircraft Corp., Windsor Locks, Connecticut, January 1970.

4. Life Support System for Space Flights of Extended Time Periods, NASA CR-614. General Dynamics, San Diego, California, November 1966.

5. Test Plan and Procedure, Operational Ninety-Day Manned Test of a Regenerative Life-Support System, NASA-LRC, NAS1-8997. McDonnell Douglas Astronautics Company, Western Division, Santa Monica, California, June 1969.

6. Parametric Study of Manned Life Support Systems, Volume 2, DAC-56713, NASA CR 73283. McDonnell Douglas Astronautics Company, Western Division, January 1969.

Critical Issues Addressed by Research Cluster

1-LS-5

WATER ELECTROLYSIS

1.1.3.1.1.2.2.2.1.1
How are the electrochemical reactions involved in the operation of water electrolysis cells affected by space-flight conditions?

1.1.3.1.1.2.2.2.1.3
What are the zero-g effects on materials required for water electrolysis cells?

1.1.3.1.1.2.2.2.1.5
How does zero-g influence the electrolytes used for water electrolysis?

1.1.3.1.1.2.2.2.1.6
How does zero-g affect the electrolysis cell components?

1.1.3.1.1.2.2.2.2.1
What are the zero-g effects on the optimum operational modes of water vapor electrolysis?

1.1.3.8.3
What are the space effects on an integrated animal EC/LS?

1.1.3.8.4
What are the space effects on the integrated EC/LS and power?

1.1.3.8.5
How does space affect an integrated life support system?

EARTH ORBITAL EXPERIMENT PROGRAM AND REQUIREMENTS STUDY

MANNED SPACEFLIGHT CAPABILITY

RESEARCH CLUSTER–1-LS-6
FOOD MANAGEMENT AND PROCESSES

C-1-224

C-1-224

RESEARCH CLUSTER SYNOPSIS—MANNED SPACEFLIGHT CAPABILITY

1-LS-6 Food Management and Processes

1. Research Objectives
The Food Management and Processes Research Cluster has as its objective the determination of optimum methods for the handling, storage, processing, and regeneration of food. This objective will be realized by the in-flight testing, measurement, and evaluation of equipment and processes designed for a zero-g space environment.

The research in this experiment group is in response to 20 critical issues categorized under the heading of Food Management, qhich were derived from the detailed analysis of a NASA long-range objective in the Life Support and Protective System, which is ". . . to develop technically and esthetically acceptable techniques and hardware . . . in the areas of food management and to develop the technology to convert metabolic wastes into food."

Data are needed for the evaluation of long-term storage of frozen, freeze dried, and irradiated canned foods, and for regeneration of food supplements from biowastes by either chemical or biological processes.

2. Background and Current Status
As stated in the NASA long-range objectives, there exists a need for storing and providing palatable and nutritional food for long-duration space missions and "In the area of space foods, physicochemical derivation of nutritious food from human waste will provide an additional means to combat food shortages in the world." Economical storage and food regeneration will materially reduce the weight of resupply required for space stations and the storage requirements for nonresupply interplanetary missions. Various types of food-storage techniques have been developed and tested in short-duration space flights (up to 2 weeks) but long-duration testing is required to assess the effects on the crew, spacecraft, and various subsystems. Processes for synthesizing edible fats were developed by Germany during World War II. More recently, NASA studies have continued to improve this process. The synthesis of proteins by chemical and microbial methods are in varying stages of development, and some testing has been carried out on humans. Experimental work on Hydrogenomonas eutropha hydrogen-fixing bacteria has reportedly been temporarily halted due to poisoning of test rats. If this research is not renewed, another food regeneration process should replace the process described in this research cluster. Performance in a typical space environment is required to ensure a workable food management system.

3. Description of Research

The food management research will be divided into two general areas — the testing of various types of stored foods and the regeneration of food from biowastes. In the first case, three types of stored food will be consumed, including freeze-dried, frozen, and irradiated. Data to be obtained include information on palatability, handling, storage requirements, energy, and water requirements. Food regeneration from biowastes will consist of testing various processes, including chemical synthesis via the glycerol process, photosynthesis from living plant cells, and biochemical reactions by such hydrogen-fixing bacteria as *Hydrogenomonas eutropha*. The data required from these processes include requirements for power, thermal energy, temperatures, flow rates, efficiencies, and chemical and microbial water potability analyses.

One experiment within this research cluster was identified and described in detail under NASA contract NAS1-9248, "Requirements Study for a Biotechnology Laboratory for Manned Earth Orbiting Missions." It was designated in that study as 4-117 Food storage, Preparation, and Feeding Methods and is described briefly in Appendix H of this report.

4. Impact on Spacecraft

Food regeneration processes are quite complicated since they require startup of processes, monitoring of equipment and operating variables, process testing, and equipment adjustment and repair. The evaluation of food regeneration processes should extend for as long as the process operates properly.

A 10-man hydrogenomonas-unit complete system is estimated to weigh 1700 lb, having a volume of 100 ft^3 and requiring 6 kw of electric power. The volume of the equipment used for the food storage techniques experiment could be kept to 100 ft^3, the weight to 2500 lb, and electric power requirements to 1 kw.

5. Required Supporting Technology Development

Food regeneration processes require much more development, particularly for equipment operation in a zero-g environment. The capabilities and limitations of biochemical reaction systems using such bacteria as *Hydrogenomonas eutropha* in the production of protein from wastes must be determined in a weightless environment. The output of such systems as a food source in support of prolonged space missions must be integrated into a food management program. Techniques for two-phase condensing of liquid from vapors in zero-g must be established and food regeneration systems must be integrated with a zero-g waste management system.

6. References

1. Parametric Study of Manned Life Support Systems, Volume 2, DAC-56713, NASA CR 73283. McDonnell Douglas Astronautics Company, Huntington Beach, California, January 1969.

2. Study of Life Support Systems for Space Missions Exceeding One Year in Duration, Phase 1A, Volumes 1 and 2, NAS2-3818. Lockheed Missiles and Space Company, Sunnyvale, California, December 15, 1967.

3. John F. Foster and J. H. Litchfield. Systems Approach to Evaluating Hydrogenomonas Cultures, NASA CR-1296. Battelle Memorial Institute, Columbus, Ohio, April 1969.

4. P. Budininkas, G. A. Remus, and J. Shapira. Synthesis of Formaldehyde from CO_2 and H_2. Paper No. 680715, Society of Automotive Engineers and Manufacturing Meeting, Los Angeles, California, October 7-11, 1968.

5. Proceedings of the Winter Study on Uses of Manned Space Flight, 1975-1985, Vol. 2. NASA Science and Technology Advisory Committee for Manned Space Flight, La Jolla, California, December 6-9, 1968.

RESEARCH CLUSTER
NO. 1-LS-6

Critical Issues Addressed by Research Cluster

1-LS-6

FOOD MANAGEMENT AND PROCESSES

1.1.3.6.1.1.1
What are the effects of zero-g on mixing of solids and/or liquids in stored freeze-dried food management processes?

1.1.3.6.1.1.2
How does zero-g influence the interfaces of stored freeze-dried food and water management systems?

1.1.3.6.1.1.3
What are the zero-g effects on stored freeze-dried food management components?

1.1.3.6.1.1.4
What are the effects of zero-g on stored freeze-dried food management subsystem?

1.1.3.6.1.2.1
What are the zero-g effects on the use of frozen foods on spacecraft water balance, water recovery system, and logistic problems?

1.1.3.6.1.2.2
What are the zero-g effects on refrigeration requirements needed for frozen food system?

1.1.3.6.1.3.1
What are the space influences on the irradiated/canned food system?

1.1.3.6.1.3.2
How does zero-g affect the interfaces of the irradiated/canned food system with the water and waste management systems?

1.1.3.6.2.1.1
What are the space effects on catalysts used in the chemical synthesis reaction chambers?

1.1.3.6.2.1.2
What are the zero-g effects on the yield obtained from glycerol food process?

1.1.3.6.2.1.3
How does zero-g influence the carbon dioxide requirements of the chemical synthesis system?

1.1.3.6.2.1.4
How does zero-g affect the high pressure processes involved in chemical synthesis food regeneration system?

1.1.3.6.2.2.1
What are the effects of a space environment on gas/liquid separation involved in biological food regeneration process?

1.1.3.6.2.2.2
What are the zero-g effects on solid/liquid separation in processed biological food management?

1.1.3.6.2.2.3
How does the space environment influence culture growth processes in processed biological food management?

1.1.3.6.2.2.4
What are the effects of zero-g on processed biological food management components?

1.1.3.6.2.2.5
What are the effects of a space environment on the processed biological food management subsystem?

1.1.3.8.3
What are the space effects on an integrated animal EC/LS?

1.1.3.8.4
What are the space effects on the integrated EC/LS and power?

1.1.3.8.5
How does space affect an integrated life support system?

EARTH ORBITAL EXPERIMENT PROGRAM
AND REQUIREMENTS STUDY

MANNED SPACEFLIGHT CAPABILITY

RESEARCH CLUSTER–1-LS-7
ATMOSPHERE PURIFICATION METHODS

C-1-229

RESEARCH CLUSTER SYNOPSIS—MANNED SPACEFLIGHT CAPABILITY
1-LS-7
Atmosphere Purification Methods

1. Research Objectives

The objective of the Atmosphere Purification Methods test is the evaluation of the optimum methods for atmospheric purification and control in providing a habitable environment for the astronaut. This research objective will be realized by the in-flight testing, measurement, and evaluation of the equipment and processes designed for a zero-g space environment. The research in this experimental group is a consequence of 30 critical issues categorized under the heading of Atmosphere Purification and Control, paragraph 1.1.3.2, Table 1 of Manned Spaceflight Capability Critical Issues. These issues were derived from a detailed analysis of the long-range NASA objective in the Life Support and Protective Systems, which is ". . . to develop techniques and hardware for maintaining the carbon dioxide, humidity, and contaminant characteristics of the cabin atmosphere within acceptable limits."

Data are needed for the evaluation of systems and processes proposed for the removal of CO_2, trace contaminants, and aerosols, and for the humidity control of the cabin air in a zero-g space environment for an extended period of time.

2. Background and Current Status

As stated in the broad NASA objectives, there exists a need ". . . to develop the technology for highly reliable systems to support and protect man . . . for long duration." In particular, future long-duration missions lacking resupply capabilities demand increasing closure of the life support system's oxygen-recovery loop, the first step being the removal of CO_2 from the cabin atmosphere. A variety of concepts have been proposed, many of which are in varying phases of development under NASA test and sponsorship. These include nonregenerative absorbers, such as LiOH with subsequent dump; or regenerative systems, such as electrodialysis, solid amines, molecular sieves, liquid absorption, and carbonation cells, which can provide both CO_2 separation and concentration for subsequent processing in oxygen-recovery systems. The NASA/MDAC 90-day manned test has evaluated a solid amine regenerative system, and molecular sieve systems had been successfully tested in the earlier NASA/MDAC 60-day run and the NASA/LRC 28-day test, among others. A more promising system is the electrochemical carbonation cell, which is still in the early stages of development.

3. Description of Research

The atmospheric purification test will consist of a test unit with associated equipment to test a number of advance CO_2 concentrator systems. The equipment will include high- and low-temperature heat-transport loops, a cabin air blower, a vacuum pump assembly, and an electric power regulation system. Parameters to be measured include liquid flows, gas flows, temperatures, pressures, and power and chemical analysis of gases and liquids. Additional data will be taken regarding maintenance, repair, and component replacement.

The experiment will consist of bringing each system to operational level and testing its performance for a variety of test conditions. The resultant CO_2 is collected, analyzed, and made available to the baseline system periodically for further processing.

One experiment within this research cluster was identified and described in detail under NASA contract NASl-9248 "Requirements Study for a Biotechnology Laboratory for Manned Earth Orbiting Missions." It was designated in that study as

4-109	Carbonation cell CO_2 collector

and is described briefly in Appendix H of this report.

4. Impact on Spacecraft
The experiment test rig and systems require a volume of 3 by 3 by 3.5 ft, weights 300 lb, and requires a maximum power level of 400 w for a three-man crew. Crew skill involves an engineering background and thorough knowledge of the CO_2 concentrator systems, since the crew will be required to assess, repair, and adjust the system being tested to each set of test conditions. The CO_2 that is collected may be either returned for further processing, used for attitude control purposes, or otherwise disposed of in such a manner so as not to interfered with preplanned mass balances of spacecraft.

A critical interface is the process size since it must operate on bypassed cabin air and this may affect and reduce the baseline system capacity, which is optimally designed for the maximum crew level. Each system is to be tested for 90 days, will require 2 hours of a crewman's time at startup for each set of test conditions and 10 percent of his time thereafter for monitoring, replacement and repair.

All parametric measurements and chemical tests are assumed to be automatic.

5. Required Supporting Technology Development
Prior to the testing of the CO_2 concentrator systems, extensive supporting research and theoretical investigations are required in the areas of zero-g boiling and condensing, zero-g liquid-vapor separation, and zero-g mass transport. Further development and design are also required for flight-type vacuum pumps, accumulators, valves and regulators, as well as automatic instrumentation for sampling and chemical analysis.

6. References

1. Proceedings of Winter Study on Users of Manned Space Flight, 1975-1985, Volume 2. NASA SP-196, NASA Science and Technology Advisory Committee for Manned Space Flight, La Jolla, California, December 6-9, 1968.

2. Aviation and Space, Progress and Prospects. ASME Annual Aviation and Space Conference, Beverly Hills, California, June 16-19, 1968.

3. Study of Life Support Systems for Space Missions Exceeding One Year in Duration, Phase 1A, Volume 1. NASA CR-73158. Lockheed Missiles and Space Company, Sunnyvale, California, December 15, 1967.

4. Life Support System for Space Flights of Extended Time Periods. NASA CR-614, General Dynamics, San Diego, California, November 1966.

5. Parametric Study of Manned Life Support Systems, Volume 2. NASA CR-73283 DAC-56713, McDonnell Douglas Astronautics Company, Western Division, January 1969.

6. O. K. Houck, L. G. Clark, C. H. Wilson, and W. D. Hypes. Recent Developments and Tests of Integrated Systems Hardware. Paper No. 70-Av/SpT-13, ASME Space Technology and Heat Transfer Conference, Los Angeles, California, June 21-24, 1970.

Critical Issues Addressed by Research Cluster

1-LS-7

ATMOSPHERE PURIFICATION METHODS

1.1.3.1.1.2.2.2.2.2.
How does weightlessness influence the effectiveness of humidity control by water vapor electrolysis on the spacecraft life support system operation?

1.1.3.1.2.2.2.2
How will zero-g affect dual-gas atmosphere pressure control when using paramagnetic sensors?

1.1.3.2.1.4.1
What are the electrochemical problem areas associated with zero-g operation of electrodialysis CO_2 collection units?

1.1.3.2.1.4.1.3
What electrolytes are best for use in zero-g electrodialysis CO_2 collection units?

1.1.3.2.1.4.1.4
How are electrodialysis CO_2 collector components affected in space?

1.1.3.2.1.4.2.1
What are the zero-g mass transport characteristics of solid amines?

1.1.3.2.1.4.2.3
How does a weightless environment affect the water vapor control required in the operation of solid amine CO_2 collectors?

1.1.3.2.1.4.2.4
How does a space environment affect the operation of the solid amine components?

1.1.3.2.1.4.3.3
How does zero-g affect the molecular sieve CO_2 collector components?

1.1.3.2.1.4.3.4
What is the effect of a space environment on integrated molecular sieve CO_2 collector subsystems?

1.1.3.2.1.4.4.1
How does zero-g influence the chemical reactions in a liquid absorption CO_2 collector?

1.1.3.2.1.4.4.2
How do space conditions affect materials required for a liquid absorption CO_2 collector?

1.1.3.2.1.4.4.6
How does zero-g affect the liquid absorption subsystem and components.

1.1.3.2.1.4.5.1
What are the zero-g effects on electrochemical transport parameters in carbonation cells?

1.1.3.2.1.4.5.3
How does weightlessness affect the electrolyte to be used in carbonation cells?

1.1.3.2.1.4.5.4
What are the zero-g affects on carbonation cell subsystem or components?

1.1.3.2.2.3.1
How does zero-g affect trace contaminants removal by nonregenerable sorbers and what are the effects on conceptual configurations?

1.1.3.2.2.3.2
How does zero-g affect trace contaminants removal by regenerable sorbers and what are the effects on conceptual configurations?

1.1.3.2.2.4.1
What are the zero-g effects on catalytic oxidation of trace contamints by high temperature catalytic burners and how do they influence the conceptual configurations?

1.1.3.2.2.4.2
What are the zero-g effects on catalytic oxidation of trace contaminants by low temperature catalytic burners and how do they influence the conceptual configurations?

1.1.3.2.3.3.2.1
How does a weightless environment influence humidity control methods?

1.1.3.2.4.2.1.1
What are the zero-g effects on aerosol filtration subsystems under space flight conditions?

1.1.3.2.4.2.1.2
How does zero-g influence on aerosol control subsystem?

1.1.3.2.4.2.2.1
How does a space environment affect the performance of aerosol precipitation subsystems?

1.1.3.2.4.2.2.2
What is the effect of zero-g on an aerosol control subsystem?

1.1.3.2.4.2.3.1
How does zero-g affect aerosol centrifugation subsystems?

1.1.3.2.4.2.3.2
What is the influence of weightlessness on an aerosol control subsystem?

1.1.3.8.3
What are the space effects on an integrated animal EC/LS?

1.1.3.8.4
What are the space effects on the integrated EC/LS and power?

1.1.3.8.5
How does space affect an integrated life support system?

EARTH ORBITAL EXPERIMENT PROGRAM
AND REQUIREMENTS STUDY

MANNED SPACEFLIGHT CAPABILITY

RESEARCH CLUSTER–1-LS-8
LIFE SUPPORT MONITORING AND CONTROL

C-1-235

RESEARCH CLUSTER SYNOPSIS—MANNED SPACEFLIGHT CAPABILITY
1-LS-8
Monitoring and Controls

1. Research Objectives

This research cluster is to acquire data relative to the display techniques, parameter monitoring, and control involved in the operation of the baseline Life Support System. The information gathered during the manned space research mission will be useful in the optimum design of subsequent display, monitoring, and control hardware for extended long-duration missions.

This research cluster is in line with the NASA specific objective under Life Support and Protective Systems which calls for the development of instrumentation and techniques for monitoring and controlling all aspects of the system and functions in order to ensure a safe, comfortable, and habitable spacecraft.

This cluster is inherent and basic to many of the critical issues listed under Life Support and Protective Systems and is related particularly to the cluster titled Maintenance and Repair.

2. Background and Current Status

Recent manned tests of Integrated Life Support Systems, ILSS, conducted by NASA/LRC and McDonnell Douglas have shown that excessive crew time is required to manually control subsystems within acceptable limits of performance; hence, automated controls must be used for sensing, checking, and altering the parameters, processes, and hardware. Included, for example, are spacecraft atmospheric constituents, pertinent hardware component functions, energy transfer, mass transfer, and fluid chemical analysis. Skylab A has 400 ILSS parameters to be sensed and monitored, but with a minimum of on-board automatic functions, while the number for future space stations will increase by orders of magnitude. The need for a data management system to reduce crew involvement time has been long recognized by NASA. Studies are in progress for the definition of data management systems. MIT has conducted a study for MSC on a dual computer configuration for acquiring subsystem information, comparing with selected values for out-of-tolerance, activating-controller, and site-isolation functions, while providing for display, storage, effects computer study for an ILSS automatic controller design, and the MDAC NASA Preliminary Design Study (NAS8-25140) includes a Data Management System definition. The philosophy and design of the control/display console awaits the results of the completion of these studies, the McDonnell Douglas 90-day Space Station Simulator test run, and future long-duration manned tests.

3. Description of Research

A detailed research cluster description was not prepared for this area since the objectives of Life Support Monitoring and Control can be achieved by observation, measurement, and subjective evaluation of operational activities involved in monitoring and control of the baseline Life Support System. The techniques for acquisition of such data are described in Research Cluster 1-BR-3 "Complex Task Behavior" and include use of TV cameras, Timers, and crew voice logs. The research consists of on-board evaluation of the Data Management System containing the monitoring, controls, display, storage, and telemetering functions at varying levels of automation and interaction. The Data Management System of Figure 1 will process the information coming to it from the analyzers and sensors, relay the information to a computer for comparison with referenced set parametric limits, display the information in an appropriate manner, telemeter the data, decide appropriate changes in parameters, and feed the information back to the parameter control loop. The crew will be involved in monitoring the data output at the control console, which will have selection switches for observing the system functions, flow diagrams, and component performance at successive levels of complexity with appropriate interrogation techniques.

The initial Data Management System will be designed to control the baseline Life Support System at a primitive level with a significant crew involvement. The objective is then gradually to merge the acquisition and comparison functions with the reduction and command functions, thereby bringing the system to a peak of automated sophistication and reducing crew participation to a minimum.

The research will determine the impact of integration on the Data Management Subsystem function and the observation of resultant life support system output parameters, system performance, and crew activities.

4. Impact on Spacecraft

The consequence of this research cluster will, as a result of exercising an ever-increasing efficient automated control and monitoring function, reduce system power demands, decrease ILS system coolant and heating requirements, reduce system weight by extending component life, reduce crew time involvement, and enhance reliability. The crew will follow the ILS response to the level of buildup of the Data Management System sophistication and will exercise override commands and adjustments where and when necessary to ensure satisfactory function.

5. Required Supporting Technology Development

Significant advances must be made both in the theory of data management and in the development of suitable hardware for its execution. As indicated, very important elements in data management are the reduction of crew involvement time and a crew-independent, continuous status diagnostic capability. Related to the

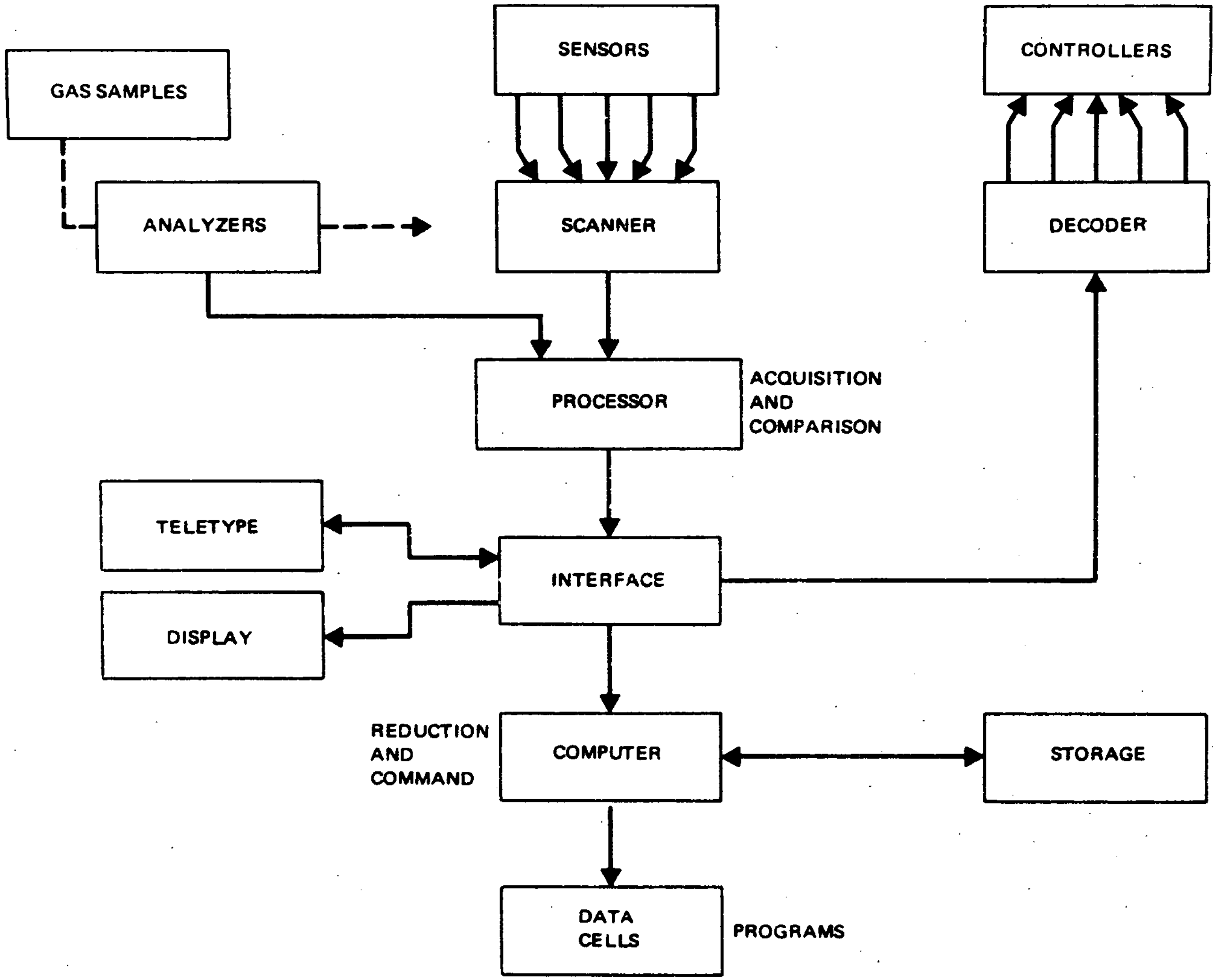


FIGURE 1 - Data Management System

latter are such capabilities as an automatic water potability monitor, a microbial detection and suppression system, and monitors of catalyst bed poisons and of contaminants in electrolysis products.

6. References

1. Test Plant Procedure, Operational Ninety-Day Manned Test of a Regenerative Life Support System. NASA-LRC Contract NAS1-8997. McDonnell Douglas Astronautics Co. Report DAC-63303, June 69 - March 1970.

2. Preliminary Systems Design Data, Volume 1 Book 3, Crew Systems. McDonnell Douglas Astronautics Co. - West,Report NAS8-25140, July 1970.

3. O. K. Houck, et al. Recent Developments and Tests of Integrated System Hardware. NASA LANGLEY Research Center, ASME Paper No. 70-Av/SpT-13, ASME Space Technology and Heat Transfer Conference, Los Angeles, California, June 1970.

4. Proposal to Study an Integrated Life Support System Automatic Controller Design. McDonnell Douglas Astronautics Co. - West, MDC - G0218P, September 1969.

Critical Issues Addressed by Research Cluster

1-LS-8

LIFE SUPPORT MONITORING AND CONTROL

1.1.3.1.1.1.3.3 What are the characteristics of fluid gaging and management in cryogenic atmosphere supply systems?

1.1.3.1.1.1.3.4 What control sensors are needed for long duration operation of two-gas atmosphere systems?

1.1.3.1.2.2.1 How will zero-g affect dual gas atmosphere pressure control when using polarographic sensors?

1.1.3.1.2.2.3 How does zero-g affect dual-gas atmosphere pressure control when using mass spectrometers?

1.1.3.1.2.2.4 How does zero-g affect dual-gas atmosphere pressure control when using gas chromatographs?

1.1.3.2.3.3.2.4 How does zero-g affect the humidity control subsystem components?

1.1.3.8.2 What are the zero-g effects on the EC/LS System Controls?

1.1.3.8.3 What are the space effects on an integrated animal EC/LS?

1.1.3.8.4 What are the space effects on the integrated EC/LS and power?

1.1.3.8.5 How does space affect an integrated life support system?

EARTH ORBITAL EXPERIMENT PROGRAM
AND REQUIREMENTS STUDY

MANNED SPACEFLIGHT CAPABILITY

RESEARCH CLUSTER–1-LS-9
WASTE MANAGEMENT

C-1-240

RESEARCH CLUSTER SYNOPSIS—MANNED SPACEFLIGHT CAPABILITY
1-LS-9
Waste Management

1. Research Objectives
The research objectives of the Waste Management experiment group are to test and evaluate various types of waste collection, handling, and disposal systems in a typical space station environment for future application to space stations and interplanetary spacecraft. Knowledge to be gained includes efficiency of the system; capability of operation in zero-g; amount of power, water, and heat required; comfort of crew; and degree of cleanliness obtained.

2. Background and Current Status
Waste management systems for the Gemini and Apollo spacecrafts have been of the bag and stow type. For longer-duration spaceflight, more elaborate methods have been under development for the collection, transfer, treatment, and storage or disposal of wastes; in particular, the fecal waste commode design involving the dry-john technique (with vacuum drying of wastes) has been under development by the NASA Langley Research Center. NASA/MSC is developing the wet-john technique with vapor compression of the fecal flush. Waste incinerators have been under development since 1961, when a three-man prototype proved their feasibility. NASA/ARC has been developing an incinerator using electrical and microwave energy. The NASA/AEC RITE Waste Management-Water system, now under development, incorporates a radioisotope-heated incinerator. Other advanced waste-management concepts include the Zimmerman wet oxidation method, which offers great potential for application to spacecraft waste processing but is still in the feasibility-demonstration development stage.

3. Description of Research
A number of different test systems will be installed in the space laboratory, replacing the spacecraft baseline waste management units for the duration of the test. The systems will be suitably instrumented (such as temperature, power, and cine camera) and tested for durations of up to a full crew cycle. Where necessary, onboard adjustments will be made to improve the system operation. The space crew will monitor sensors, flows, and power requirements, collect samples of effluents for bacteria and chemical tests, and perform routine maintenance as required.

Five experiments within this research cluster were identified and described in detail under NASA contract NAS1-9248, Requirements Study for a Biotechnology Laboratory for Manned Earth Orbiting Missions. These were designated in that study as

2-112	Advanced personal hygiene concepts
4-113	Spillage handling and recovery
4-115	Vacuum drying waste management system

4-116 RITE waste management system

4-120 Personal hygiene systems

and are described briefly in Appendix H of this report.

4. Impact on Spacecraft

The extended-duration testing of the systems will require heat rejection, power, and oxygen consumption requirements that may not have been allocated to spacecraft baseline systems. The volume of the experiment is 100 ft^3, the total test system weight is 900 lb, and the power requirement is estimated at 500 w for a three-man system. The by-product gases must be either dumped overboard periodically or used in a biowaste electric propulsion system. The by-product solids are stored for return to Earth.

The crew must have an engineering background and possess familiarity with life support systems, operations, and tests. A fully automated test experiment will require one man to start up and monitor each unit for approximately 2 hours, and for 1 hour per day thereafter for monitoring of output data.

Each unit will be subjected to varying conditions of flow rates, heating, cooling, and pressures (subject to the discretion of the test conductor), and tested for periods up to one crew cycle.

5. Required Supporting Technology Development Research and technological advances are required in the areas of materials, catalysts, zero-g two-phase liquid/gas separation, and heat transport, which are pertinent to various components of waste management systems. Research is also needed in the evaluation of known waste management concepts such as aerobic and anaerobic biodegradation, gamma irradiation, and wet oxidation, relative to their integration into functional life support systems.

6. References

1. Aviation and Space, Progress and Prospects. ASME Annual Aviation and Space Conference, Beverly Hills, California, June 16-19, 1968.

2. Study of Life Support Systems for Space Missions Exceeding One Year in Duration, Phase 1A, Volume 1. NASA CR-73158, Lockheed Missiles and Space Company, Sunnyvale, California, December 15, 1967.

3. Life Support System for Space Flights of Extended Time Periods. NASA CR-614, General Dynamics, San Diego, California, November 1966.

4. Parametric Study of Manned Life Support Systems, Volume 2. NASA CR-73283, DAC-56713, McDonnell Douglas Astronautics Company, Western Division, January 1969.

5. R.B. Jagow, R.J. Jafee, and C.G. Saunders. The Processing of Human Wastes by Wet Oxidation for Manned Spacecraft. A.S.M.E. Paper No. 70-Av/SpT-1, Space Technology and Heat Transfer Conference, Los Angeles, California, June 21-24, 1970.

6. G.C. Schaedle and G.E. Laubach, An Introduction to the Waste Management Problem for Large Space Stations. A.S.M.E. Paper No. 70-Av/SpT-24, Space Technology and Heat Transfer Conference, Los Angeles, California, June 21-24, 1970.

Critical Issues Addressed by Research Cluster

1-LS-9

WASTE MANAGEMENT

1.1.3.5.1.1.1 What are the zero-g phase separation and liquid fluid flow characteristics, involved in urine collection?

1.1.3.5.1.2.1 What are the zero-g flow characteristics involved in feces and refuse collection?

1.1.3.5.2.1 How does zero-g influence mass transfer in waste management incineration?

1.1.3.5.3.1.1 What are the effects of zero-g on the basic processes involved in urine storage in waste management systems?

1.1.3.5.3.1.2 How does zero-g affect chemical and freeze urine storage methods?

1.1.3.5.3.2.1 What are the space effects on fluid flow in conjunction with drying and/or mixing in feces and refuse storage systems?

1.1.3.8.3 What are the space effects on an integrated animal EC/LS?

1.1.3.8.4 What are the space effects on the integrated EC/LS and power?

1.1.3.8.5 How does space affect an integrated life support system?

1.2.1.4.1.3 What methods will be used to dispose of used paper?

1.2.1.4.2.7 What disposal facilities will be required for used photographics?

1.2.1.7.4.2 What space station disposal techniques would be adaptable to consuming or reusing the unwanted microfilm records?

1.3.2.5.2 What are the disposal techniques required for:

A. housekeeping debris/dust
B. clean-up hardware
C. damaged or discarded components

EARTH ORBITAL EXPERIMENT PROGRAM AND REQUIREMENTS STUDY

MANNED SPACEFLIGHT CAPABILITY

RESEARCH CLUSTER—1-LS-10
HEAT TRANSPORT EQUIPMENT

C-1-344

RESEARCH CLUSTER SYNOPSIS—MANNED SPACEFLIGHT CAPABILITY
1-LS-10
Heat Transport Equipment

1. Research Objectives

The objective of the Heat Transport Equipment Experiment Group is the design of optimum heat transfer components and circuits for the transport of thermal energy in a spacecraft environment, with minimum weight, volume, and power requirements and with maximum reliability. This objective will be realized by the in-flight evaluation of test components and systems subject to the thermal stresses and heat loads of a typical space environment for extended durations under zero-gravity conditions.

The research included in this experiment group is addressed to 24 critical issues categorized under the heading of Thermal Control, which was derived from a detailed analysis of the NASA long-range objectives under Life Support and Protective Systems which indicates the need "...to develop thermal techniques for environmental thermal control/life support systems, including the provision of thermal energy...and the removing and rejection of waste heat from the atmosphere, the EC/LS, and the electronic and experimental equipment."

The heat-transfer components and circuits will involve not only solid conduction paths, but also gases, liquids, and two-phase flow mixtures for the transport of thermal energy in a zero-g environment without natural convection. Data on the performance of the systems under actual test conditions of space are the only reliable means of ensuring adequate system design and long-duration mission success.

2. Background and Current Status

As stated in the NASA Scientific and Technological Objectives, the goals are "...to conduct tests and studies pertinent to the development and design criteria for habitation, life support, and protective equipment for men in long-duration space operations." Such objectives require the thermal control of the life support system and habitation area via heat-transport or cooling circuits capable of removing source heat and distributing it to the desired thermal sinks, using air circuits for crew comfort, waste heat circuits, and low-temperature coolant loops. These generally consist of gas or fluid handling heat-transport loops, which transport the heat via thermal conduction, forced convection, radiation, condensing and evaporation, or boiling processes in two-phase flow. In the past, limited experimental work on heat transport and boiling in near zero-g has been studied by ground simulation, drop towers, and short-duration airflights. More complex integrated loops have been studied, and the NASA McDonnell Douglas Space Station Simulator 90-Day test incorporates a complex heating and cooling system with a simulated space sink. As previously stated, however, the performance data are incomplete because (1) ground tests are subject to gravity and natural convection, and (2) short-duration zero-g tests are limited in scope. The early designs for space applications avoided the zero-g effects or unknowns, where possible, for example by restricting radiator coolant loops to a single liquid phase, thus suffering large weight penalties. A thorough knowledge of zero-g two-phase condensation flow would, on the other hand, permit the design of lighter-weight radiators and heat-transfer circuits.

3. Description of Research
The research will be directed at obtaining performance data on heat-transport equipment, single loops, and integrated loops. The experiment will utilize a heat-transport test facility containing the various heat-transport components with provisions for interconnection through a variety of valves, loops, and circuits. The tests will include the testing of basic hardware and components, and their integration into loops of increasing complexity. The components will test both active and passive thermal-control techniques, including insulation, radiative surfaces, heat pipes, heat storage, phase change, condensers, and evaporation. The loops will be selectively tied in with the baseline source or sink loops as well as with the baseline cabin air loop.

Parameters to be measured include temperatures, fluid flow, pressures, moisture content, heat-transfer rates, and power.

Three experiments within this research cluster were identified and described in detail under NASA contract NAS1-9248 "Requirements Study for a Biotechnology Laboratory for Manned Earth Orbiting Missions." These were designated in that study as

4-110	Advance control and monitoring of microbiol levels in life support systems
4-111	Comfort zone and cabin air distribution evaluation
4-112	Water condenser-separator characteristics

and are described briefly in Appendix H of this report.

4. Impact on Spacecraft
The experiment should have only a minor impact on spacecraft resources or normal activities. The crew will be involved in startup, shutdown, circuit or loop switching, maintenance, and occasionally, monitoring of test parameters. The experiment will be controlled by automatic equipment, and test data will be recorded on tape and visual displays. In-flight assessment or evaluation of the test data may result in the substitution of a component or loop into the baseline system for the duration of the mission.

The weight of the test rig and associated display/controller is 700 lb, the volume is 40 ft^3, and the power is estimated at 1.0 Kw. The crew will require an engineering background and will involve 10 percent of his time daily.

5. Required Supporting Technology Development
Before the space experiment is conducted, a variety of ground tests will have been performed in heat-transport hardware designed for processes associated with condensation, boiling, and vapor/liquid separation for a zero-g environment. The theory for flow instability, film instability, multiphase flow phenomena in steady and transient conditions will have been developed, and ground-hardware tests will be performed.

6. References

1. Life Support System for Space Flights of Extended Time Periods. NASA CR-614, General Dynamics, San Diego, California, November 1966.

2. Heat Transfer, Section VI. Aviation and Space, Progress and Prospects. Annual Aviation and Space Conference, Beverly Hills, California, June 16-19, 1968, pp 77-85.

3. Symposium on Fluid Mechanics and Heat Transfer Under Low-Gravity Conditions. Lockheed Research Laboratories, Palo Alto, California, June 24-25, 1965.

4. Analysis, Criteria Development, and Design of an Orbital Condensing Heat Transfer Experiment, Vol. 2. NAS8-21005, Airesearch, Los Angeles, California.

5. Engineering Criteria for Spacecraft Cabin Atmosphere Selection, DAC-59169, Douglas Missile and Space Systems Division, Santa Monica, California, November 1966.

6. Parametric Study of Manned Life Support Systems, Volume 2. DAC-56713, McDonnell Douglas Astronautics Company, January 1969.

Critical Issues Addressed by Research Cluster

1-LS-10

HEAT TRANSPORT EQUIPMENT

1.1.3.1.1.1.3.2 What is the long-term effectiveness of present cryogenic storage methods?

1.1.3.1.1.2.1.2 What are the effects of zero-g heating on the operation of the molten carbonate reactor?

1.1.3.1.1.2.2.1.1.1 What are the zero-g heat transport problems involved in the operation of the Sabatier reactor?

1.1.3.1.1.2.2.1.2.1 What are the zero-g heat transfer problems involved in the operation of the Bosch reactor?

1.1.3.2.1.4.2.2 What are the heat transfer problems involved in the zero-g operation of solid amine CO_2 collection units?

1.1.3.2.1.4.5.2 What are the zero-g effects on heat transfer conditions in carbonation cells?

1.1.3.2.3.3.2.3 What are the effects of zero-g on heat transfer involved in humidity control subsystems?

1.1.3.3.1.1.1.1 How does zero-g influence the convection heat transfer in high vacuum insulation?

1.1.3.3.1.1.2.2 How does zero-g affect the convection heat balances in ablative insulations?

1.1.3.3.1.1.2.3 How does zero-g influence the chemical reaction rates of ablative insulation systems?

1.1.3.3.1.1.3.1 What is the influence of a space environment on heat path characteristics of conduction type insulation used in a space vehicle structure?

1.1.3.3.1.2.1.1 How does a space environment influence materials on fixed radiative surface systems?

1.1.3.3.1.2.2.1 What are the effects of space on mechanisms and materials used with variable surface insulation?

1.1.3.3.1.3.1 What are the effects of zero-g on heat transfer involved in boiling and/or condensation processes in heat pipes?

1. 1. 3. 3. 2. 1. 1. 1. 1 How does zero-g affect solar heat collectors and interfaces with the heat storage systems?

1. 1. 3. 3. 2. 1. 1. 1. 2 How does a space environment influence waste heat utilization in heat storage systems?

1. 1. 3. 3. 2. 1. 1. 1. 3 How does a space environment affect heat storage components?

1. 1. 3. 3. 2. 1. 1. 2. 1 How does a space environment influence the applications, heat load and temperature ranges used in a single-phase heat storage system?

1. 1. 3. 3. 2. 1. 1. 2. 2 What are the effects of zero-g on single-phase storage systems and components?

1. 1. 3. 3. 2. 1. 2. 1 What are the effects of a space environment on radio-isotope management and control characteristics used with fluid transport systems?

1. 1. 3. 3. 2. 2. 1. 2. 1. 1 How does zero-g influence the condensing heat transfer characteristics in space radiators?

1. 1. 3. 3. 2. 2. 1. 2. 1. 2 How does zero-g affect the configurations of condensing space radiators?

1. 1. 3. 3. 2. 2. 2. 2. 1 How does zero-g affect condensing heat transfer?

1. 1. 3. 3. 2. 2. 2. 2. 2 What are the effects of a space environment on liquid/gas separation in condenser systems?

1. 1. 3. 4. 2. 2. 2. 1 What are the zero-g heat transfer effects involved in a vapor diffusion process?

1. 1. 3. 4. 2. 2. 3. 1 What are the effects of zero-g on heat transport in the vapor diffusion compression process?

1. 1. 3. 4. 2. 2. 4. 1 What are the space effects on heat transfer problems in the vapor pyrolysis process?

1. 1. 3. 4. 2. 2. 5. 1 How does zero-g affect vapor compression process?

1. 1. 3. 8. 3 What are the space effects on an integrated animal EC/LS?

1. 1. 3. 8. 4 What are the space effects on the integrated EC/LS and power?

1. 1. 3. 8. 5 How does space affect an integrated life support system?

EARTH ORBITAL EXPERIMENT PROGRAM
AND REQUIREMENTS STUDY

MANNED SPACEFLIGHT CAPABILITY

RESEARCH CLUSTER—1-LS-11
CREW EQUIPMENT AND PROTECTIVE SYSTEMS

C-1-249

RESEARCH CLUSTER SYNOPSIS—MANNED SPACEFLIGHT CAPABILITY
1-LS-11
Crew Equipment and Protective Systems

1. Research Objectives

The objective of the Crew Equipment and Protective Systems experiment group is the evaluation of crew equipment and protective systems, such as those required for the detection and control of, and protection against, fire, temperature extremes, biological and atmospheric contaminants, fluid spills, radiation, and hazards caused by space vacuum and meteroids. This objective will be realized by testing the various subsystems, including space suits, with simulated hazards (when advisable) under spaceflight conditions in a zero-g environment.

The research in this group is addressed to the critical issues categorized under 1. 1. 3. 7 Crew Protective Systems, which were derived from an analysis of the NASA long-range objectives in Life Support and Protective Systems. High reliability and sensitivity of these detection, control, and protection systems must be demonstrated under actual flight conditions since systems of this type must be used to ensure crew safety on long-term missions.

2. Background and Current Status

An integrated crew protective equipment system is not available in the current state of the art. Many specific instruments are available commercially for various areas of the experiment. For example, fire-detection sensors, such as infrared and ultraviolet sensors, smoke alarms, and the condensation nuclei counter, are currently being developed for space use; and fire-suppression techniques, such as CO_2, halocarbons, inert flooding, and atmosphere dumping, have been investigated experimentally. Leak-detection techniques for use in space, such as ultrasonic sensors, liquid crystals, pressure sensors, and the two-gas atmosphere controller, are under development, as well as techniques for repairing various types of leaks including those caused by meteoroids.

Radiation detectors are currently available (some already qualified), and shielding facilities and techniques are merely a design problem. The technology for the detection of atmospheric contaminants is well developed for flight, but further work will be required to develop more-sensitive methods for trace quantities. Bacteriological sensors still rely on slow culturing techniques; some devices, however, are being developed for the instantaneous detection of biological materials.

Soft space suits have evolved from aircraft pressure suits to the Apollo suit with its lunar environment protection capabilities.

Hard suits have also been under development, and operational prototypes have been manufactured by such organizations as Litton Industries and NASA's Ames Research Center. Currently MDAC is developing an emergency space suit undergarment which provides passive cooling via water evaporation to vacuum. Astronaut maneuvering units are also in varying stages of development including hand held devices and those attached to the suit.

3. Description of Research

The research cluster is designed to evaluate the various advance crew and protective systems. The bulk of the experiments will be conducted in an enclosed hazard-controlled laboratory section, completely isolated from the baseline system. For example, tests of fire propagation, detection, and control will be conducted on a small scale within a bell jar in a remote handling laboratory; the fluid spill, detection, repair, and clean-up test will be conducted on a larger scale in a fluid-hazard handling section to evaluate fluid component repair kits, cabin air filters, and spill clean-up techniques. Space suits will be worn during toxic-fluid spill-hazard experiments, and during the performance of extravehicular activities and man-machine research experiments. The astronauts will provide subjective evaluations of comfort, mobility, and dexterity in the space suits. Also, included will be the evaluation of such life support parameters as metabolic data, mass balances, temperatures, pressures, suit atmosphere compositions, relative humidity, and microbial analyses. The space suit evaluations thus performed will impose only minimum penalties on the spacecraft systems.

Two experiments in this research cluster were identified and described in detail under NASA control NAS1-9248, Requirements Study for a Biotechnology Laboratory for Manned Earth Orbiting Missions. In that study, they were designated as

4-118	Protective clothing and IVA suit assemblies
4-119	EVA suit and biopack systems

These experiments are described briefly in Appendix H of this report.

4. Impact on Space

This research activity will have little impact on the space station since it will be completely isolated from the baseline system. Electrical power will be required to operate test equipment, motor, fans and pumps. Hot and cold fluid loops must also be introduced into the facility. The facility will measure 10 by 10 by 10 ft, have access to vacuum, and require 500-w maximum power.

The time required to actually conduct the tests will vary from a few minutes to several hours. Setting up experiments and cleaning up will require additional man-hours. The crew will also evaluate experiment results during and after the tests. All test materials and fluids will be stored in the facility with no anticipated replacement.

5. Required Supporting Technology Development
Prior to the space test, the components, sensors, alarms, and hardware associated with the crew equipment and protective systems must be tested in a simulated spacecraft environment. Studies of flame propagation, fire detection and control, and fluid spillage and clean up, however are, gravity influenced, and therefore, the effects cannot be known until space-tests have been completed in a zero-g environment. In addition, the requirement for biological and particle control of cabin air extends beyond the usual gaseous contaminants and includes the need for development of a microbial detection and suppression system.

6. References

1. H.C. Vykukal. Advanced Development in Hard Suit Technology. Aviation and Space, Progress and Prospects. Annual Aviation and Space Conference, Beverly Hills, California, June 16-19, 1968.

2. Final Report on RX-1, RX-2, and RX-2-A Suit Development. Publication No. 4259. Litton Systems, Inc., Beverly Hills, California, 1965 (Confidential).

3. D.L. Richardson. Research to Advance Extravehicular Protective Systems. Air Force Report No. AMRL-TR-66-250, April 1967.

4. Proceedings of the National Conference on Space Maintenance and Extravehicular Activities. Orlando, Florida, March 1-3, 1966.

Critical Issues Addressed by Research Cluster

1-LS-11

CREW EQUIPMENT AND PROTECTIVE SYSTEMS

1.1.3.7.1.1.1 What are the zero-g effects on the spacecraft atmosphere dump subsystem?

1.1.3.7.1.1.2 How does zero-g affect the carbon dioxide fire control subsystem under space flight conditions?

1.1.3.7.1.1.3 What are the effects of zero-g on a fluorocarbon fire control subsystem?

1.1.3.7.1.1.4 What are the effects of zero-g on an inert gas flood fire control subsystem under space flight conditions?

1.1.3.7.1.4.1 What is the effect of zero-g on the personal hygiene subsystem?

1.1.3.7.2.1.1 What changes occur in the operation of the artificial gravity subsystem (centrifuge and/or vehicle rotation) under space flight conditions?

1.1.3.7.2.1.2 What changes occur in the operation of the cardiovascular conditioning subsystem under space flight conditions?

1.1.3.7.2.2.1 What are the space effects on the radiation shielding subsystem?

1.1.3.7.2.2.2 What are the space effects on the radiation shelter subsystem?

1.1.3.7.2.2.3 What are the space effects on radiation suits?

1.1.3.7.2.3.1 How does space affect the various methods of rapid repressurization of spacecraft cabins?

1.1.3.7.2.3.2 What are the effects of space on the leak detection subsystem?

1.1.3.7.2.3.3 What are the space effects on the leak repair subsystem?

1.1.3.7.2.3.4 What are the space effects on the EVA suit subsystem?

1.1.3.7.2.4.1 What are the effects of space vacuum on crew protection by the use of the atmospheric supply and purification system functions?

1.1.3.7.2.4.2 How does a space environment influence the flexible airlocks and space suits subsystems?

1.1.3.8.3 What are the space effects on an integrated animal EC/LS?

1.1.3.8.4 What are the space effects on the integrated EC/LS and power?

1.1.3.8.5 How does space affect an integrated life support system?

EARTH ORBITAL EXPERIMENT PROGRAM AND REQUIREMENTS STUDY

MANNED SPACEFLIGHT CAPABILITY

RESEARCH CLUSTER—1-LS-12
LIFE SUPPORT SYSTEM MAINTENANCE AND REPAIR

C-1-254

RESEARCH CLUSTER SYNOPSIS—MANNED SPACEFLIGHT CAPABILITY
1-LS-12
Maintenance and Repair

1. Research Objective
The object of this research cluster is to develop optimum techniques and hardware for the maintenance and repair of the life support system. The information to be gathered is in the categories of equipment maintenance, repair, and retrofit, and will consist primarily of observing the effectiveness of crew operations in a zero-g environment while performing the above functions on the baseline system.

This research cluster is related to the NASA broad objective of developing "...technology for highly reliable systems to support and protect man and to enhance his capability to perform operations." It is specifically directed toward the extension of mission life, minimization of system weight, and decreasing the time required for the crew to perform routine maintenance and repair. The maintenance and repair group is addressed to critical issues listed under Paragraphs 1.1.3.8 and 1.3.2 in Table 1 of Appendix B.

2. Background and Current Status
Life support and equipment design relies heavily on optimum techniques of routine maintenance, replacement and repair to ensure a high degree of reliability, long life, minimum weight, maximum crew safety, and minimum interference with crew activities. Advance life support concepts and systems, which are in varying stages of development and test, are subject to occasional module or component failures, which presumably will also occur in a spacecraft. NASA has supported studies (References 1 and 2) in the area of maintainability to establish guidelines relating to design of equipment for scheduled maintenance, spares, parallel-redundancy, unscheduled maintenance, modularity, and reliability. McDonnell Douglas has conducted recent studies on life-support equipment maintenance (Reference 3), initiated on IRAD investigation on a water electrolysis unit failure life test, and is currently maintaining and gathering data from life support systems in the 90-Day Space Station Simulator Test. This information is necessary for the design of equipment and maintenance procedures; however, the requirement still exists to conduct zero-g space testing to verify the design and procedures and to uncover unforseen difficulties inherent in zero-g space operation, particularly related to repair, spillage, and component replacement.

3. Description of Research
The maintenance tasks for this experiment group will be conducted as part of other experiment groups, particularly 1-BR-3, 1-MM-5, and 1-OE-2. Based on the previous analysis and hardware test

results, the baseline life support system will be optimally designed for in-space rapid modular component disconnect, replacement, or repair. The taskboard described in Experiment Group 1-MM-5 will be used for the handling of hardware components removed from the equipment. The taskboard will be instrumented for component fault diagnostics and repair in zero-g. Electrical, mechanical, and fluid transmission elements will be analyzed and broken down to subcomponent level for part replacement and subsequent assembly. Examples of testing include valve signatures via electrical signals, pump performance, and temperature sensor response. Detailed records will be kept of components involved; time for removal, test, repair, and replacement; plus the difficulties encountered in accomplishing the task. The observations will include both taskboard operations and site maintenance. Unscheduled maintenance (e.g., hot fluid line rupture) will also be subjected to detailed annotation. In addition to written records, television and film monitoring of the maintenance operations will also be employed.

One experiment within this research cluster was identified and described in detail under NASA contract NAS1-9248, "Requirements Study for a Biotechnology Laboratory for Manned Earth Orbiting Missions." It was designated in that study as

4-121 Leak detection

and is described briefly in Appendix H of this report.

4. Impact on Spacecraft

As previously indicated, this research is associated with the baseline system maintenance, repair, and retrofit procedures. The observational data from in-space zero-g operation will lead to the design of long-lived, reliable equipment for long-duration space missions. Presumably, the crew will have been trained to perform normal maintenance and to take emergency procedures in the case of unscheduled failures. Specific impact on spacecraft resources involves the catastrophic failure of toxic fluid containers and lines, and the spillage into the cabin. Rapid detection, isolation, repair, and cleanup are necessary to reduce adverse effects on the performance of the air circulation and filtration system, to prevent clogging of hardware, electrical shorts, and excessive loss of fluid inventory, and to safeguard the crew. The routine maintenance impact on the spacecraft resources involves the maintenance taskboard located in an isolated area containing electric power sources, cooling loops, operating fluid loops, signal generators, diagnostic equipment, tools, and zero-g hold-down devices.

Routine maintenance should require 10 percent of the crew's time. Catastrophic failures of mechanical components and parts (such as valves and lines) may be quickly repaired by replacement kits, requiring only minutes per event.

5. Required Supporting Technology Development

To implement the program of maintenance and repair, the follow following supporting research and technology developments are necessary: (1) a significant amount of data must be acquired from long-life testing of prototype life-support systems to define modes of failure, failure rate, and maintenance and repair procedures; (2) A capability must be developed to detect incipient component or module failure in situ. Such capabilities are represented by automatic water potability monitors, a microbial detection and suppression system and monitors of catalyst bed poisons and of contaminants in electrolysis products. (3) An automatic detection, alarm, and isolation computer control system must be designed and tested with subsequent integration of monitoring and protective equipment into an integrated system.

6. References

1. Maintainability of Manned Spacecraft for Long-Duration Flights, Volumes 1, 2, and 3. NAS 2-3705, The Boeing Company Space Division, Seattle, Washington, July 1967.

2. A Study of Space Mission Duration Extension Problems, Vol III. SD 67-478-3, Space Division, North American Rockwell, October 30, 1967.

3. Preliminary Systems Design Data, Vol. 1. Space Station Preliminary Design: Book 3, Crew Systems. NAS 8-25140, McDonnell Douglas Astronautics Company–West, Huntington Beach, California, July 1970.

4. Experiment Integration Requirements Document. Experiment M507, Garrity Substitute Workbench, MSFC, June 30, 1969.

Critical Issues Addressed by Research Cluster

1-LS-12

LIFE SUPPORT SYSTEM MAINTENANCE AND REPAIR

1.1.3.7.2.4.3 What are the space effects on the leak detection and repair subsystem for protection from space vacuum?

1.1.3.8.1 What are the zero-g effects on maintenance and repair procedures?

1.1.3.8.3 What are the space effects on an integrated animal EC/LS?

1.1.3.8.4 What are the space effects on the integrated EC/LS and power?

1.1.3.8.5 How does space affect an integrated life support system?

TABLE 1. LEGEND OF CODES USED IN CREW ACTIVITY MATRICES

Table 1 is an explanation of the codes used in the following matrices. The matrices summarize the inflight crew tasks required to conduct and support the research identifited in the synopses.

TYPE OF ACTIVITY

0 - Not covered below

1 - Experimental subject

2 - Spacecraft operations

3 - Preexperiment equipment preparation

4 - Maintenance of equipment

5 - Conduct of experiment

6 - Evaluate intermediate results

7 - Direct observation of phenomena

8 - Data handling

9 - Communications; initiate and receive transmissions (telemetry, voice)

CREW SKILL

0 - No special skill required

1 - Medicine

2 - Biology

3 - Physiology

4 - Psychology

5 - Engineering

6 - Astronomy

7 - Physics

8 - Oceanography

9 - Forestry

10 - Agriculture

11 - Geology

12 - Meteorology

13 - Geography

14 - Cartography

15 - Hydrology

16 - Navigation

17 - Communications

18 - Radiology

19 - Instrumentation

20 - Photography

21 - Astronaut

22 - Other

Each code includes the first one or two digits describing the discipline and a second code letter describing level of skill: A for highest skill level (requires professional training with degree or advanced degree in discipline such as M. D.): B for semiprofessional, the traditional technician level requiring several years of training; C for technician level which requires some special training.

Research Cluster
No. 1-LS-1

CREW ACTIVITY MATRIX

RESEARCH CLUSTER NO.		TASK DESCRIPTION	EXPERIMENT EQUIPMENT	TYPE OF ACTIVITY	PECULIAR ENVIRONMENTAL REQUIREMENTS	EXCLUSIVE	CREW SKILL	FREQUENCY	TASK TIME (MIN)	NO. OF CREWMEN	START	DURATION	TASK CONCURRENCY
1-LS-1	(1)	Actuate sensors and recording equipment	at console	3		X	5-C	1/week	10	1	1974	2	
	(2)	Actuate heater and cooling circuits	"	3		X	5-C	"	10	1	"	2	
	(3)	Adjust tank liquid vapor separation membrane	"	3		X	5-C	"	15	1	"	2	
	(4)	Focus and adjust camera/TV equipment and lights	"	3		X	5-C	"	30	1	"	2	
	(5)	Adjust 'g' level by reaction control system override command	"	2		X	5-B	"	30	1	"	2	
	(6)	Switch on test sample heater	"	3		X	5-C	"	5	1	"	2	
	(7)	Adjust heater level to desired boiling regime	"	5		X	5-A	"	15	1	"	2	
	(8)	Conduct boiling experiment on sample	"	5		X	5-A	"	5	1	"	2	
	(9)	Terminate experiment and shut down equipment	"	5		X	5-B	"	30	1	"	2	
	(10)	Evaluate intermediate results	"	6		X	5-A	"	60				
	(11)	Repeat steps (1) through (10) for rest of samples	"										

Research Cluster
No. 1-LS -2

CREW ACTIVITY MATRIX

RESEARCH CLUSTER NO.	TASK DESCRIPTION	EXPERIMENT EQUIPMENT	TYPE OF ACTIVITY	PECULIAR ENVIRONMENTAL REQUIREMENTS	EXCLUSIVE	CREW SKILL	FREQUENCY	TASK TIME (MIN)	NO. OF CREWMEN	START	DURATION	TASK CONCURRENCY
1-LS 2 (1)	Actuate sensor and data handling equipment	from console	8		X	5-C	Once	15	1	1974	2	
(2)	Actuate heater and cryogenic sink loop flow rates	"	3		X	5-C	"	15	1	"	2	
(3)	Switch on and adjust lights	"	3		X	5-C	"	15	1	"	2	
(4)	Adjust and focus TV and high speed camera	"	3		X	5-B	"	30	1	"	2	
(5)	Initiate liquid pump flow in condensor tube	"	3		X	5-C	"	30	1	"	2	
(6)	Adjust 'g' level by reaction control system and hold	"	5		X	5-C	"	30	1	"	2	
(7)	Adjust heat, flow rate and pressure in tube	"	5		X	5-A	"	60	1	"	2	
(8)	Conduct experiment and monitor variables	"	5		X	5-A	"	180	1	"	2	
(9)	Terminate experiment	"	5		X	5-C	"	30	1	"	2	
(10)	Analyze recorded data	data output	6		X	5-A	"	40 hr	1	"	2	
(11)	Repeat for new set of operating conditions											

CREW ACTIVITY MATRIX

RESEARCH CLUSTER NO.	TASK DESCRIPTION	EXPERIMENT EQUIPMENT	TYPE OF ACTIVITY	PECULIAR ENVIRONMENTAL REQUIREMENTS	EXCLUSIVE	CREW SKILL	FREQUENCY	TASK TIME (MIN)	NO. OF CREWMEN	START	DURATION	TASK CONCURRENCY
1-LS-3 + (1)	Actuate sensors & recording equipment	from console	3		X	5-C	1/3 mo.	15	1	1975	2	
(2)	Actuate heater & coolant circuits	"	3		X	5-C	"	15	1	"	2	
(3)	Actuate supply process loop to be tested	"	3		X	5-A	"	15	1	"	2	
(4)	Adjust operating parameters	"	5		X	5-A	1/week	30	1	"	2	
(5)	Conduct test	"	5		X	5-C	contin-uous	3 mos.	1	"	2	
(6)	Perform routine scheduled maintenance	"	4		X	5-C	1/week	60	1	"	2	
* (7)	Monitor output data	"	5		X	5-B	1/day	15	1	"	2	
(8)	Evaluate intermediate results	"	6		X	5-A	1/week	120	1	"	2	
(9)	Terminate experiment	"	5		X	5-C	1/3 mo.	30	1	"	2	
(10)	Repeat 1-8 for the remaining two supply process systems											
	Note: Three Processes Loops to be tested											
+	System operation and control assumed completely automatic with manual override											
*	Continuous first 2 hrs.											

CREW ACTIVITY MATRIX

RESEARCH CLUSTER NO.	TASK DESCRIPTION	EXPERIMENT EQUIPMENT	TYPE OF ACTIVITY	PECULIAR ENVIRONMENTAL REQUIREMENTS	EXCLUSIVE	CREW SKILL	FREQUENCY	TASK TIME (MIN)	NO. OF CREWMEN	START	DURATION	TASK CONTINGENCY
1-LS-4 +(1)	Actuate Sensors & recording equipment	from console	3		X	5-C	1/3 mo.	15	1	1975	2	
(2)	Actuate heater & coolant loops	"	3		X	5-C	"	30	1	"	2	
(3)	Actuate automatic water sampling & test equipment	"	3		X	5-C	"	30	1	"	2	
(4)	Actuate water management system to be tested	"	5		X	5-B	"	15	1	"	2	
(5)	Adjust parameters (temp, flow, press, heating & cooling)	"	5		X	5-A	1/week	30	1	"	2	
(6)	Conduct test (90 days)	"	5			5-B		continuous	1	"	2	
*(7)	Monitor output data	"	5		X	5-B	1/8 hr	30	1	"	2	
(8)	Perform routine scheduled maintenance		4		X	5-C	1/week	60	1	"	2	
(9)	Evaluate results		6		X	5-A	1/week	120	1	"	2	
(10)	Terminate Experiment	"	5		X	5-B	1/3 mo.	30	1	"	2	
(11)	Repeat (1) to (10) for rest of water management test systems											
+	All automatic including water sampling & testing											
*	Continuous first 2 hours											

RESEARCH CLUSTER
NO. 1-LS-5

CREW ACTIVITY MATRIX

RESEARCH CLUSTER NO.	TASK DESCRIPTION	EXPERIMENT EQUIPMENT	TYPE OF ACTIVITY	PECULIAR ENVIRONMENTAL REQUIREMENTS	EXCLUSIVE	CREW SKILL	FREQUENCY	TASK TIME (MIN)	NO. OF CREWMEN	START	DURATION	TASK CONCURRENCY
1-LS-5 + (1)	Actuate sensors & recording equipment	from console	3		X	5-C	1/3 mo.	15	1	1975	2	
(2)	Actuate heater & coolant flow loops	"	3		X	5-C	"	30	1	"	2	
(3)	Actuate gas & water sample tester equipment	"	3		X	5-B	"	30	1	"	2	
(4)	Actuate water electrolysis system to be tested	"	3		X	5-B	"	15	1	"	2	
* (5)	Adjust test parameters (flow, power, temps, etc.)	"	5		X	5-A	1/week	30	1	"	2	
(6)	Conduct test (90 days)		5			5	continuous				2	
(7)	Monitor output data	"	5		X	5-B	1/8 hr.	30	1	"	2	
(8)	Perform routine scheduled maintenance		4		X	5-C	1/week	60	1	"	2	
(9)	Evaluate test data		6		X	5-A	1/week	120	1	"	2	
(10)	Terminate experiment	"	5		X	5-B	1/3 mo.	30	1	"	2	
(11)	Repeat (1) to (10) for remaining water electrolysis processes											
+	All automatic operation including test analysis											
*	Two hours during startup.											

CREW ACTIVITY MATRIX

RESEARCH CLUSTER
NO. 1-LS-6

RESEARCH CLUSTER NO.	TASK DESCRIPTION	EXPERIMENT EQUIPMENT	TYPE OF ACTIVITY	PECULIAR ENVIRONMENTAL REQUIREMENTS	EXCLUSIVE	CREW SKILL	FREQUENCY	TASK TIME (MIN)	NO. OF CREWMEN	START	DURATION	TASK CONCURRENCY
1-LS-6 *(1)	Check biowaste for mass accumulation	at console	3		X	5-C	1/week	5	1	1975	2	
(2)	Initiate sensor, recording and analytical instruments	at console	3		X	5-C	once	10	1	1975	2	
(3)	Initiate heating and cooling loops	at console	3		X	5-C	once	30	1	1975	2	
(4)	Switch on electric power to system	at console	3		X	5-C	once	5	1	1975	2	
(5)	Activate pumps, blowers, and valves	at console	3		X	5-C	once	5	1	1975	2	
(6)	Activate nutrient feed line	at console	5		X	5-C	once	5	1	1975	2	
(7)	Adjust operating parameters	at console	5		X	5-A	1/8 hr	60	1	1975	2	
(8)	Monitor test data and system parameters	at console	5			5-B	1/8 hr	30	1	1975	2	
(9)	Evaluate test data	at console	6		X	5-A	1/week	120	1	1975	2	
(10)	Perform scheduled maintenance and repair		4		X	5-B	1/week	60	1	1975	2	
(11)	Terminate experiment	at console	5		X	5-B	once	30	1	1975	2	
(12)	Repeat (1) through (11) for each net set of operating parameters											
	*System operation and control assumed completely automatic with optional override											

CREW ACTIVITY MATRIX

RESEARCH CLUSTER
NO. 1-LS-7

RESEARCH CLUSTER NO.	TASK DESCRIPTION	EXPERIMENT EQUIPMENT	TYPE OF ACTIVITY	PECULIAR ENVIRONMENTAL REQUIREMENTS	EXCLUSIVE	CREW SKILL	FREQUENCY	TASK TIME (MIN)	NO. OF CREWMEN	START	DURATION	TASK CONCURRENCY
1-LS-7 *(1)	Switch on sensors and recording instruments		3		X	5-C	once	10	1	1975	2	
**(2)	Switch on air sampler and analyzer instruments		3		X	5-C	once	10	1	1975	2	
(3)	Switch on fans, blowers, pumps		3		X	5-C	once	10	1	1975	2	
(4)	Start test loop flow		5		X	5-B	once	30	1	1975	2	
(5)	Adjust operating parameters		5		X	5-B	1/8 hr	60	1	1975	2	
(6)	Monitor parameters		5		X	5-A	1/8 hr	30	1	1975	2	
(7)	Analyze test data		6		X	5-A	1/week	120	1	1975	2	
(8)	Perform scheduled maintenance and repair		4		X	5-B	1/week	60	1	1975	2	
(9)	Terminate test		5		X	5-B	once	30	1	1975	2	
(10)	Repeat (1) through (9) for remaining systems to be tested											
	*System parameters are automatically controlled including test sampling of air with optional control override.											
	**All monitoring and control performed at console.											

CREW ACTIVITY MATRIX

RESEARCH CLUSTER NO.	TASK DESCRIPTION	EXPERIMENT EQUIPMENT	TYPE OF ACTIVITY	PECULIAR ENVIRONMENTAL REQUIREMENTS	EXCLU-SIVE	CREW SKILL	FREQUENCY	TASK TIME (MIN)	NO. OF CREWMEN	START	DURA-TION	TASK CONCURRENCY
1-LS-9 *(1)	Switch on sensors and recording equipment		3		X	5-C	once	10	1	1974	2	
+(2)	Switch on heater and coolant loops		3		X	5-C	once	30	1	1974	2	
(3)	Switch on electric power to pumps, fans, motors, etc.		3		X	5-C	once	10	1	1974	2	
(4)	Switch on sampling and test instrumentation		3		X	5-C	once	30	1	1974	2	
(5)	Switch on electric heaters		3		X	5-C	once	10	1	1974	2	
(6)	Conduct waste management experiment		5		X	5-B	once/ 2 hr	15	1	1974	2	
(7)	Repair and maintain equipment		4		X	5-B	1/week	60	1	1974	2	
(8)	Adjust operating parameters		5		X	5-A	1/day	30	1	1974	2	
(9)	Evaluate results		6			5-A	1/week	60	1	1974	2	
(10)	Terminate experiment		5		X	5-B	once	30	1	1974	2	
**(11)	Repeat (1) through (10) for each waste management system to be tested.											

*Equipment automatic with optional override.

+All controls and displays at test console.

**Each system to be tested for 3 months.

CREW ACTIVITY MATRIX

RESEARCH CLUSTER NO. 1-LS-10

RESEARCH CLUSTER NO.	TASK DESCRIPTION	EXPERIMENT EQUIPMENT	TYPE OF ACTIVITY	PECULIAR ENVIRONMENTAL REQUIREMENTS	EXCLUSIVE	CREW SKILL	FREQUENCY	TASK TIME (MIN)	NO. OF CREWMEN	START	DURATION	TASK CONCURRENCY
1-LS-10 *(1)	Switch on sensor and recording equipment		3		X	5-C	once	5	1	1974	2	
(2)	Actuate power to fans, blowers, motors, etc.		3		X	5-C	once	5	1	1974	2	
(3)	Actuate coolant heat sink and source loops		3		X	5-C	once	30	1	1974	2	
(4)	Actuate fluid flow looks and heat exchangers		5		X	5-B	once	30	1	1974	2	
(5)	Adjust test parameters		5		X	5-A	1/8 hr	60	1	1974	2	
(6)	Monitor test data		5		X	5-B	1/8 hr	30	1	1974	2	
(7)	Perform scheduled maintenance and repair		4		X	5-B	1/week	60	1	1974	2	
(8)	Evaluate test data		6		X	5-A	1/week	120	1	1974	2	
(9)	Terminate experiment		5		X	5-B	once	30	1	1974	2	
(10)	Repeat (1) through (9) for each new set of operating parameters and component loop set-up.											
	*Parameters automatically controlled with optional override.											

CREW ACTIVITY MATRIX

RESEARCH CLUSTER
NO. 1-LS-11

RESEARCH CLUSTER NO.	TASK DESCRIPTION	EXPERIMENT EQUIPMENT	TYPE OF ACTIVITY	PECULIAR ENVIRONMENTAL REQUIREMENTS	EXCLU-SIVE	CREW SKILL	FREQUENCY	TASK TIME (MIN)	NO. OF CREWMEN	START	DURA-TION	TASK CONCURRENCY
1-LS-11 (1)	Set up test samples and equipment		3	*	X	5-B	once	60	1	1974	1	
(2)	Switch on sensors and recording equipment		3		X	5-C	once	10	1	1974	1	
(3)	Adjust lighting and focus camera TV		3		X	5-C	once	60	1	1974	1	
(4)	Switch on pumps and blowers and fans		3		X	5-C	once	10	1	1974	1	
(5)	Adjust "g" level		3		X	5-B	once	30	1	1974	1	
(6)	Ignite sample/cause fluid skill		5		X	5-B	once	10	1	1974	1	
+(7)	Actuate fire control		5		X	5-B	once	1	1	1974	1	
(8)	Repair fluid line break		5		X	5-B	once	3	1	1974	1	
(9)	Clean up		5		X	5-B	once	10	1	1974	1	
(10)	Evaluate results		6		X	5-A	once	60	2	1974	1	
(11)	Repeat (1) through (10) for [illegible] set of											
	new [illegible]											
	*Requires remote enclosed handling hazard area											
	with windows.											
	+Automatic sensor activation											

EARTH ORBITAL EXPERIMENT PROGRAM
AND REQUIREMENTS STUDY

MANNED SPACEFLIGHT CAPABILITY

RESEARCH CLUSTER—1-EE-1
DATA MANAGEMENT

C-1-269

RESEARCH CLUSTER SYNOPSIS - MANNED SPACEFLIGHT CAPABILITY

1-EE-1
Data Management

1. Research Objectives

This engineering experiment research cluster includes research addressed primarily to the evaluation of data-management hardware and associated equipment designed for on-orbit processing, storage, retrieval, and display of experimental data in manned space vehicles. It is also concerned with the interface between man-machine and data-management hardware, with the objective of determining human-engineering design criteria, improving procedures, and evaluating man's capabilities.

NASA long-range objectives that this research will attempt to achieve include the development of:

A. Equipment and procedures to assure the effectiveness of man in the pursuit of science experiments, applications tasks, and vehicle operations.

B. Techniques to conduct activities in support of major scientific and applied disciplines.

C. Space station modules that can support laboratories and observations for the pursuit of science, applications, and technology goals.

In the data-management area, systematic analysis of the NASA objectives led to the identification initially of 220 critical issues under the headings of computers, specialized data processes, computer programs, data storage, data collection and retrieval, and data transmission. Further investigation revealed that a number of these critical issues would be answered by other experiment groups and an additional substantial number were more appropriate for investigation in ground-based research facilities or by ground-based analysis techniques. After this screening and commonality analysis, 22 critical issues remained for investigation under this research cluster. Upon detailed analysis of these 22 critical issues and several attempts to define an engineering experiment to answer them, it became evident that they all could be best answered by the observational techniques described in Research Cluster 1-OE-5 "Vehicle Support Operations."

2. Background and Current Status

Long-duration, multimanned, scientific and technological space missions will accumulate huge amounts of raw data. On past space flights, most of the data were transmitted to Earth for reduction and analysis, with relatively little on-board processing; however, two conditions militate against this procedure for future flights.

First, the absolute mass of data and the broad-band nature of much of the data make almost impossible demands on practically any forseeable data-transmittal system. Second, the optimum uses of man's scientific capability in space dictates that he perform onboard evaluation of data to change experiments in process, where the nature of the data so indicates.

Beginning with Mercury and progressing through the Gemini and Apollo vehicle systems, the astronauts have had to interact with the onboard computer systems at an increasingly sophisticated level. The relative amount of this interaction and the skill with which the astronauts have adapted to it are a source of gratification to mission planners; but more importantly, they are predictive of the extensive participation that can be expected of man in the data-management processes of the future.

Computer-generated data, which must be viewed by the crew to support an autonomous decision-making policy as well as become a part of a mission profile log, could be conveniently put on microfilm to alleviate the paper consumption, storage, and logistics problems associated with the use of on-line printers. Technical manuals, reports, books, and engineering drawings that must be viewed by the crew for vehicle subsystem maintenance and experiment support can also be microfilmed to avoid the storage problems that would occur if these materials are left in their original form. Present microfilm facilities, although widely used in industry, have not been evaluated as a data and library source for use in a zero-gravity environment.

Photographic data, common to practically all of the research clusters defined in this study, will constitute perhaps the major type of data with which flight crews must interface. This interface will include not only the actual collection of data by loading and unloading cameras and taking pictures, but also the processing of such data, including film processing, reduction and enlargement, editing, and evaluating for adequacy.

3. Description of Research

The research in this cluster addresses the man-machine interface, and as such, it measures psychological parameters including visual clarity of displayed information, comprehensive speed of digital presentation, and verbal comments associated with access time of stored microfilm and other data.

One aspect of the procedural involvement in this research cluster requires the visual display of microfilm that has been processed in a zero-gravity environment and verification of the adequacy of the crew to microfilm interface through direct observation and subjective comments of the crewman subject. This procedure will allow observation of the quality of zero-gravity processing as well as the manned participation. Scoring data will be measured and recorded via the computer experimental programs as well as the verbal comments supplied to an audio recorder. The microfilm facility will also serve as a library source of information for the crew. Evaluation of its success in this capacity will be measured through qualitative comments and measurement of the elapsed time required for microfilm request and display.

With the long-lead development times of hardware for this research cluster, it appears that research specifically in this area cannot be started until about 1976, but after its inception it should be continued for about 4 years.

Crew participation in this research cluster requires that crewmen act as experimental subjects interfacing with the data-management hardware. This will require the equivalent of 3.5 hours per week for one crewman through the life of the research program.

4. Impact on Spacecraft

The impact of this research on the spacecraft is negligible since the equipment, which includes a microfilm storage facility, a camera, a CRT display, a microfilm enlarger, a microfilm processor, a keyboard control unit, an audio recorder, and computer interface units, is assumed to be spacecraft operational equipment.

The primary interface that the equipment makes with the vehicle subsystems is via the space vehicle computer. This interface requires both a hardware interface unit and supporting computer programs.

Crew involvement in experiment support is limited to normal replacement of required processing chemicals.

5. Required Support Technology Development.

Data-management engineering research requires ground-based development and test of space-qualified devices, such as a microfilming facility. Other types of hardware developments envisioned include (1) devices for viewing, editing, cropping, and selectively transmitting such data as filmed terrain observations; (2) devices for compressing data; and (3) devices for providing enhanced communication with computers.

6. References

1. Scientific and Technical Objectives, Earth Orbital Experiment Program and Requirements Study. L13-9852, NASA Langley Research Center, Hampton, Virginia, July 28, 1969.

2. Earth Orbiting Experiment Program and Requirements Study. First Interim Report, MDC G0549, April, 1970.

Critical Issues Addressed by Research Cluster

1-EE-1
DATA MANAGEMENT

1. 2. 1. 2. 2. 8
What type of personal and/or group microfilm reader, and what kind of film retrieval techniques will be required on the space vehicle?

1. 2. 1. 4. 2. 6
What peripheral accessories will be required, such as lenses, exposure meters, special setups for microfilming, microfilm quick access, etc. ?

1. 2. 1. 5. 2. 4
What magnification systems could be utilized to enlarge microminiaturized printing?

1. 2. 1. 5. 2. 5
What comparative advantages could be shown for micro-miniature printout rolls, sheets, or cards?

1. 2. 1. 5. 2. 6
What access techniques could be used for repetitive needs if the printouts were rolls, sheets, or cards?

1. 2. 1. 5. 2. 7
What techniques would be best to provide duplicate or multiple copies?

1. 2. 1. 5. 3. 1
What microfilming equipment would be adaptable for the use of space station permanent data storage?

1. 2. 1. 5. 3. 2
What are the effects of zero-g on microfilming equipment; and what revisions would have to be accomplished to make developing and processing film practical in space?

1. 2. 1. 5. 3. 6
What manned operational problems will be confronted on the microfilming storage system?

1. 2. 1. 5. 6. 2
What alternate techniques like Polaroid microfilming might replace notebooks and their accumulation of investigator data?

1. 2. 1. 5. 6. 3
What type of rapidly erasable sheets could be developed to be used in conjunction with Polaroid-type microfilming?

1.2.1.5.6.4
What type of CRT short-time (1 day maximum) storage displays could be developed which could reduce the quantity of paper storage and paper expendables (this to be used in conjunction with microfilming)?

1.2.1.5.6.5
What kind of personal quick-access microfilm reading equipment would be adaptable for the experimenters?

1.2.1.5.6.6
What kind of work effectiveness would be gained or lost by the use of the specialized personal storage and retrieval devices?

1.2.1.5.6.8
What special problems will arise in the use of personal data storage and retrieval devices in a zero-g environment?

1.2.1.5.7.3
What are the optimum techniques or methods for preparation of astronomical photographic data prior to permanent earth transmission and storage?

1.2.1.5.7.4
What are the optimum techniques or methods for preparation of analog data prior to permanent earth transmission and storage?

1.2.1.7.1.5
What photographic and/or microfilming techniques need be considered to preserve the displayed CRT information/data?

1.2.1.7.1.7
What short-time electronic storage banks would better link the CRT displays to the experimenter in his evaluation and processing of data?

1.2.1.7.2.2
What role could micro character printers with associated CRT enlargers play in digital printout subsystems?

1.2.1.7.4.1
What temporary microfilming process would have a comparative advantage over permanent microfilming?

1.2.1.7.4.3
What manned operational problems will be confronted on the microfilming retrieval system?

EARTH ORBITAL EXPERIMENT PROGRAM AND REQUIREMENTS STUDY

MANNED SPACEFLIGHT CAPABILITY

RESEARCH CLUSTER—1-EE-2
STRUCTURES

C-1- 274

RESEARCH CLUSTER SYNOPSIS—MANNED SPACEFLIGHT CAPABILITY

1-EE-2
Structures

1. Research Objectives

The objective of this research cluster is to obtain in-orbit experimental data on the dynamic characteristics of advanced structural concepts including deployable, expandable, extendable, and rotating structures of the type used in solar cell arrays, large antennas, extendable booms, and expandable tunnels, airlocks, and shelters. The major purposes of the research are (1) to obtain design data applicable to a variety of structural concepts, (2) to determine means of extending the life of such structural systems, and (3) to reduce requirements for crew time and resupply.

This research is in response to critical issues that were identified through detailed analysis of the following NASA long-range objectives:

A. To develop and operate space vehicle modules that could accommodate up to 12 men and can support laboratories and observatories for the pursuit of science, applications, and technology goals.

B. Design, develop, and flight test critical long-lead items and procedures required for planetary missions.

C. Fly an operating space vehicle module continuously for durations typical of planetary flight times to obtain data for establishing design criteria for manned systems.

2. Background and Current Status

Because of launch constraints and the stresses of flight to orbital altitude, considerable attention has been given to structural concepts that involve compact packaging of elements at launch with subsequent deployment after orbit attainment. Experience in space flight to date, mainly with unmanned vehicles, has verified the feasibility of these concepts for small sensors, antennas, and power generating devices. Utilizing this concept for large complex manned spacecraft introduces problems of the dynamics of very large deployable structures. Design data are needed on mechanisms for deploying structures, on orientation mechanisms, on large diameter dynamic space seals, lubricant stability at high temperature and low pressure, and thermal control. Orientation mechanisms have been used for small solar arrays such as those used on NIMBUS and large arrays are currently being developed and ground tested. An extensive ground-based test program should precede space testing of these devices, but in-space data are needed to verify ground developed criteria.

Many of the questions requiring flight verification will be answered in operational spaceflight conditions with experiments such as those described in Research Cluster 1-OE-3 "Assembly and Deployment." Other questions require in-space answers before structures can be designed and built for operational space use.

3. Description of Research
The research contemplated in this research cluster can be performed using as experimental equipment (1) the basic mechanisms required for the deployment and operation of large solar cells, (2) prototype expandable airlocks, tunnels, or experiment bays, and (3) extendable booms for positioning various sensors. Research activities will include monitoring of the operating parameters of the systems and observation of procedures for deployment and retraction, startup, shutdown, maintenance, and replacement of system components. The parameters to be measured include the sensing of temperatures, pressures, voltages, currents, frequencies, and speeds for rotating machinery; the measurement of dimensions in the deployed and retracted modes; and the assessment of crew performance in interfacing with the structures. Visual observations, augmented perhaps by TV camera coverage, are addressed to visual inspection of motors, bearings, seals, and gimbals; sequences of assembly, disassembly, deployment, retraction, and stowage; and crew use of expandable structures. Samples of lubricant will be taken manually and tested for degradation of lubricating quality and material traces from wear in mechanical components.

4. Impact on Spacecraft
The spacecraft must provide the sensors, displays, and controls required for system monitoring and control and any required TV cameras and video tape equipment. The crew must also devote varying lengths of time to startup, shutdown, maintenance, and replacement.

The spacecraft must accommodate the weight and volume of the experimental structural equipment in the stowed condition and provide for deployment of the structure. This will involve penetrations of the shell of the space vehicle through which the structural elements will be deployed. Viewing ports will be required for direct observation of the deployment and operation of these structural devices.

Electrical power requirements for experiments of this type are 550 watts average and 1,000 watts peak power.

5. Required Support Technology Development
Special supporting research and technology requirements do not exist.

6. References

1. Scientific and Technical Objectives, Earth Orbital Experiment Program and Requirements Study. L13-9852, NASA Langley Research Center, Hampton, Va., July 28, 1969.

2. Electrical Power Subsystem, DR8. Space Station Subsystem Definition, Vol. V, Book 1. 1 May 1970, McDonnell-Douglas Astronautics Company, May 1, 1970.

3. Photovoltaic Power Systems on Flight Spacecraft, Nimbus 2. NASA CR-62045 Document No. 685D4222, February 23, 1968.

4. OLSCA - Orientation Linkage for a Solar Cell Array. Technical Report AFAPL-TR-68-76, July 1968.

5. R. B. Beltz, H. G. Meach, and A. C. Lee. OGO Solar Array Design, Fabrication and Flight Performance. Proceedings of the 1967 Intersociety Energy Conversion Engineering Conference, pp. 235-246.

6. Manned Mission Photovoltaic Power System Study. NAS9-5266, June 9, 1967.

7. French, Robert J.: Feasibility Investigation of Expandable Structures Module for Orbital Experiment - Artificial G. NASA CR-66351, June 1967.

8. Berg, Kenneth G.: Design and Construction of an Expandable Airlock. NASA CR-66709, September 1968.

9. Goodyear Aerospace Corporation: Contract NASI-9112, Materials Technology Advancement Program for Expandable Manned Space Structures. NASA CR-66949, August 1970.

10. Tynan, Charles I. Jr.; Williams, Jerry G.; and Osborne, Robert S.: Expandable Structures Technology for Manned Space Applications. AAS/AIAA Variable Geometry and Expandable Structures Conference (Anaheim, California). April 21-23, 1971.

Critical Issues Addressed by Research Cluster

1-EE-2
STRUCTURES

1.2.2.1.1.1
Deployment mechanism performance.

1.2.2.1.1.2
Array dynamics during deployment.

1.2.2.1.1.3
Thermal gradients and distortions as a function of orbit position.

1.2.2.1.1.4
Measurement of effects of thermal cycling and thermal shock on substrates.

1.2.2.1.1.7
Effect of shock loads on deployed array.

1.2.2.1.1.8
Gimballing mechanism accuracy, reliability and performance.

1.2.2.1.1.9
Slip ring design and power transfer.

1.2.2.1.2.1
Performance evaluation of silicon cells.

1.2.2.1.2.2
Performance evaluation of thin film CdS cells.

1.2.2.1.2.3
Effects of micrometeoroids on cover glasses.

1.2.2.1.2.4
Effect of ionized radiation on cells, adhesives, and cover glasses.

1.2.2.1.2.6
UV reflective coating performance.

1.2.2.1.3.1
Roll-out deployment mechanism performance and reliability for multiple cycling.

1.2.2.1.3.2
Membrane and array deployment dynamics.

1.2.2.1.3.4

Thermal gradients and distortions as a function of orbit position.

1.2.2.1.3.5

Effect of shock loads on deployed array.

1.2.2.1.3.9

Roll-up Arrays—Gimballing Mechanism Performance and Reliability.

1.3.3.2.3.1

What are the most effective designs for expandable structures using various internally pressurized elements applicable to the design of auxiliary structures such as crew transfer tunnels, airlocks, maintenance hangars, experiment bays, or living quarters?

Consider:
- (a) Packaging requirements/techniques
- (b) Packaged bulk
- (c) Deployment aids—pressure/techniques
- (d) Rigidization requirements/techniques
- (e) Man rated requirements
- (f) Retraction requirements/techniques

RESEARCH CLUSTER SYNOPSIS – MANNED SPACEFLIGHT CAPABILITY

1-EE-3
Stabilization and Control

1. Research Objectives

The stabilization and control research cluster has as its objective the acquisition of engineering design and crew performance data through inflight testing and evaluation of advanced spacecraft attitude reference and linear acceleration measurement devices and advanced momentum storage and reaction control systems. This broad objective is detailed in the 20 specific critical issues identified through indepth analysis of the following NASA long range objectives:

A. Develop long duration systems that use high reliability components to minimize resupply and repair requirements.

B. Develop equipment and procedures to assure the effectiveness of man in the pursuit of science experiments, applications tasks, and vehicle operations.

C. Flight test critical long-lead items and procedures required for planetary missions.

The identified critical issues which encompass a broad range of technologies comprise the following categories:

A. Acquisition and fine pointing of astronomy experiments.

B. Disturbances affecting experiment stabilization.

C. Thruster exhaust plume contamination.

D. Zero-g effects on expulsion, solubility/permeation, and venting.

E. Purge/decontamination procedures and requirements.

F. Biowaste resistojet capability.

Acquisition and fine pointing of astronomy experiments present a significant problem. Analytic studies and digital-analog simulations will provide valuable information on stabilization and control system capability; however, limitations in modeling the system reduce the confidence that the system will perform as desired. Earth-based tests utilizing actual hardware are limited by gravity effects and earth disturbances. The isolation and description of these disturbances in terms of magnitude and frequency requires a vast amount of analysis which must be verified by on-orbit experimentation.

Control systems utilizing momentum storage such as control moment gyros (CMG's) or propulsion reaction control thrusters, though extensively Earth tested, still require space testing to verify the predicted performance.

2. Background and Current Status
A variety of attitude reference sensors are in various stages of development. These include gyros, laser gyros, telescopic sensors, and electromagnetic suspension systems, the object being to prevent drift from an initial reference setting.

Perkin-Elmer has performed an analytic study and simulations of a magnetic suspension system which demonstrated pointing capability of a few arc seconds. The goal of 0.01 sec was not achieved because of limited optical attitude sensors. However, the Perkin-Elmer studies do provide a good basis from which to predict the need for and define further studies, simulations and/or on-orbit experiments.

An experiment scheduled for Skylab A will measure forces imparted to the spacecraft by typical crew motion disturbances. This experiment should provide valuable data for the disturbances imparted by a single astronaut, but provides no data on disturbances imparted by the total crew. Guidelines for future crew motion disturbance experiments and the need for such experiments will be provided by Skylab A.

Control moment gyros (CMG's), which provide primary control actuation for both Space Station and unmanned experiment modules, are being developed concurrently by the Air Force and the NASA. Unfortunately, much of the Air Force work is classified and the majority of effort has been devoted to single gimbal CMG (SGCMG). Tradeoff studies indicate double gimbal CMG (DGCMG) are preferred for most Space Station and experiment module applications. Skylab A operation will provide much useful information on CMG performance but does not answer questions concerning CMG maintenance, repair, etc.

The propulsion area covers propellant tankage, feed system purge and decontamination, thruster hardware and plume contamination effects. Thrust levels range from the millipound to the multipound level, using monopropellants, bipropellants, cryogenics in chemical thrusters, and biowaste life support system byproduct gases in an electric thruster. The chemical bipropellant thrusters are well along in development and have been demonstrated successfully on the Apollo vehicles. Monopropellant thrusters have flown on satellites, while the biowaste resistojet is in the hardware development stages. However, the areas associated with long life, exhaust plume contamination, zero-gravity effect on tank surface tension devices, pressurant permeation, etc., await actual space environment testing.

3. Description of Research
The proposed research involves (1) the testing of various advanced type attitude reference systems and accelerometer devices mounted in the spacecraft or detached modules, (2) defining the acceleration disturbances inherent in spacecraft operations, and (3) testing the space vehicle control system.

Parameters to be measured in the attitude reference systems include gyro drift, gyro gimbal angles, rates, rate of spin, etc., and the error inherent in these measurements.

Acceleration disturbances involve the breakdown of the total disturbance into the individual disturbances, their frequency and magnitudes. Accelerometers will be mounted to sense and feed the data to a computer for subsequent analysis.

Testing of the vehicle control system includes the long-term testing of a momentum storage device such as an advanced CMG or an advance reaction control thruster, including a biowaste electric propulsion system. The control system when being exercised would replace or augment the baseline control system for varying lengths of time during which performance data would be taken and maintenance performed. Three experiments, representative of this research cluster, were selected for more detailed analysis. These are experiments numbered 1-EE-3-1 Drift Measurement of Groscopic Attitude Controls, 1-EE-3-2 Disturbance Torque Measurements, and 1-EE-3-3 Biowaste Electric Propulsion.

4. Impact on Spacecraft

Experiments to be flown on unmanned experiment modules require a space research facility design which accommodates these modules. The space research facility design must provide for module deployment, retrieval, docking, maintaining the module on-station, remote monitoring of experiment and provide access to the module while docked. The impact to the research facility would be significant if the design to accommodate modules were for experimental purposes only. Crew time and skill levels required for all the functions associated with module and experiment operation will be significant.

Maintenance and repair functions will not significantly impact the space research facility unless extra CMG's are required for experimental purposes. Each extra CMG for a typical 12-man space vehicle results in weight and volume penalties of 293 lb and 12.5 ft^3, respectively. Other extra equipment would have significantly reduced weight and volume penalties. Skill levels and crew time to develop and test maintenance, repair and replacement will be significant for the more involved and intricate functions. TV cameras utilized to monitor the various functions will be time shared with other experiments.

The zero-gravity experiments will have little impact on the space research facility, and can probably be accomplished in conjunction with the physics experiments. The plume contamination experiment requires careful planning to ensure proper specimen location and firing/measurement coordination, but the impact on crew and systems is minimal, as is weight, power, and volume. The primary impact caused by the biowaste resistojet experiment is power. Each thruster uses up to 150 watts during operation. Allowing two thrusters plus collection pumping power (≈25 watts), up to 325 watts could be required. However, this would only be required occasionally. The basic system operation can be ascertained with thrusters operating on a cold flow (or at least reduced-power) mode. Weight and volume estimates are 200-lb and 50-ft^3, respectively. The purge/decontamination experiment requires careful planning due to the toxic nature of the fluid (non-toxic substitutes may be used in early phases of the experiments), but otherwise, the impact is minimal. Actual propellant is required to determine catalyst bed performance and life under low pressures and propellant concentrations. Overboard expulsion (through a typical thruster) is required.

5. Required Supporting Research and Technology
Development of a flight-rated biowaste resistojet is required prior to a flight experiment, and ground system tests should be conducted before implementing the flight experiment.

6. References

1. Space Station, MSFC-DRL-160, Line Item 8, Space Station Definition, Volume V, Subsystems, Book 5 - Utility Services, MDC G0605, Prepared under Contract NAS8-25140, July 1970.

2. Space Station Phase B Definition Study, Experiments and Accommodations, Preliminary Definition of Experiment Modules, Prepared for McDonnell Douglas Astronautics Company under Subcontract No. MDAC-WD-69-4-016, March 6, 1970.

3. Proposal to Establish Supporting Research and Technology Priorities for High-Resolution Optical Telescopes. DAC-58161P, August 1968.

4. Orbital Astronomy Support Facility Study, Prepared for the NASA by McDonnell Douglas Astronautics Company under Contract NAS8-21023, June 28, 1968.

5. Angular Resolution Requirements for Orbital Astronomy by J. W. Wechsler and K. Kerr, presented to the Society of Photo-Optical Instrumentation Engineers, Unversity of California at Santa Barbara, September 24-25, 1969.

6. Resistojet System Studies Directed to the Space Station/Base, NAS1-10127, June 1970, McDonnell Douglas Astronautics Company.

7. Carl R. Halbach. Technology Development of a Biowaste Resistojet, NAS1-9474, Marquardt Corporation, June 1970.

8. M. Goodman and M. M. Yakut, Advance Biowaste Electric Propulsion Systems, ASME 1970 Space Technology and Heat Transfer Conference, Los Angeles, California, June 1970.

9. Rocket Exhaust Plume Contamination Study, FO4611-70-C-0076, R. P. L., McDonnell Douglas Astronautics Western Division, July 1970.

10. Scientific and Technical Objectives, Earth Orbital Experiment Program and Requirements Study, L13-9852, NASA Langley Research Center, Hampton, Virginia, July 28, 1969.

Critical Issues Addressed by Research Cluster

1-EE-3-1
DRIFT MEASUREMENT OF GYROSCOPIC ATTITUDE CONTROLS

1.2.3.2.1.1.1.1
What is the nominal accuracy of attitude gyros in the operational space environment?

1.2.3.2.1.1.1.2
How does the zero-g environment affect the drift of inertial devices?

1.2.3.2.1.1.1.3
How does the space environment affect sensor reliability?

1.2.3.2.1.2.1.1
What is the nominal accuracy of rate gyros in the operational space environment?

1.2.3.2.1.2.1.2
How does the zero-g environment affect the drift of inertial devices?

1.2.4.1.2.3
How does a near zero-g environment affect the drift and drift predictability of both the gyros and accelerometers?

Critical Issues Addressed by Research Cluster

1-EE-3-2

DISTURBANCE TORQUE MEASUREMENTS

1.2.3.1.1.1.1
What are the magnitudes and profiles of aerodynamic force and moment acting on space stations of certain basic shapes (including fixed and gimbaled solar panels)?

1.2.3.1.1.5.1
What disturbances are generated by the circulation of large amounts of liquid as in EC/LS systems?

1.2.3.1.2.1.1
What are the magnitude and frequency characteristics of typical crew motion perturbations?

1.2.3.1.2.4.1
What is the vibration environment generated by rotating devices (e.g., centrifuge, generators)?

1.2.3.1.2.5.1
What range of loads are generated during docking maneuvers?

Critical Issues Addressed by Research Cluster.

1-EE-3-3

BIOWASTE ELECTRIC PROPULSION

1.2.3.3.1.2.4.2
What thrust levels are best suited for control and are these thrusters best used with CMG's?

1.2.3.3.1.2.4.4
What are the material, thermal and electrical problems?

1.2.3.3.1.2.4.5
How does one improve the thruster design in order to reduce electric power requirements?

1.2.3.3.1.2.4.6
How well does the thruster perform during off design operation?

1.2.3.3.1.4.1.1
What are the thruster material problems associated with the biowastes?

1.2.3.3.1.4.1.2
What are the life support recovery cycle biowaste compositions and mass production rates?

1.2.3.3.1.4.1.3
What are the interface storage and feed system design requirements?

1.2.3.3.4.1.4
To what extent will the contaminants in the plume degrade the vehicle surface and how may this be minimized?

1.2.3.3.1.4.1.5
What are the electric power requirements and controls?

EARTH ORBITAL EXPERIMENT PROGRAM AND REQUIREMENTS STUDY

MANNED SPACEFLIGHT CAPABILITY

RESEARCH CLUSTER-1-EE-4
NAVIGATION AND GUIDANCE (4 PARTS)

C-1-287

RESEARCH CLUSTER SYNOPSIS--MANNED SPACEFLIGHT CAPABILITY
1-EE-4
Navigation and Guidance

1. Research Objectives

The long-range plans of NASA envision a large permanent general-research, development, and operational facility in which systems and equipment can be qualified for manned-spaceflights of very long duration. The research in this research cluster concentrates on that portion of the long-range objectives that deals with navigation and guidance hardware and man's contribution to the effectiveness of its use. In particular, it deals with hardware for acquiring, tracking, and obtaining nadir angle and range data on ground-based landmarks. Specific experiments are concerned with the experimental evaluation in space of advanced navigation and guidance hardware concepts that require space verification before they can command sufficient confidence to be committed to actual long-duration manned missions.

The critical issues to which this research cluster is addressed were developed by systematic, detailed analysis of NASA long-range objectives and a survey of navigation and guidance systems, subsystems, and components now in the planning or early design phases. Critical issues were developed in response to the following NASA specific objectives to perform the following:

1. Develop equipment and procedures to assure the effectiveness of man in the pursuit of science experiments, application tasks, and vehicle operations.

2. Incorporate the capability to support space operations, such as providing services to satellites or remotely operated modules.

3. Develop long-duration systems that use high-reliability components to minimize resupply and repair requirements.

Illustrative experiments for this experiment group were identified. They include 1-EE-4-1 Onboard Laser Ranging, 1-EE-4-2 Interplanetary or Translunar Navigation by Spectroscopic Binary Satellite, 1-EE-4-3 Landmark Tracker Orbital Navigation, and 1-EE-4-4 Navigation/Subsystem Candidate Evaluation.

2. Background and Current Status

In general, the basic theory relating to the navigation and guidance devices contemplated for this research cluster is well established, and in most cases experimental designs of hardware have been built. What is needed is design and fabrication of flight-type hardware items and in-flight evaluation of hardware and the man-machine interfaces.

Navigation by satellite has been well developed for ground-based and shipboard use. With inclusion of an onboard computer and the requisite receivers, a space vehicle can use the navigation satellites to determine its position and velocity, and therefore its orbital parameters. For greater distances; i. e., translunar or interplanetary orbits, the orbiting navigation satellite takes on the aspects of a spectroscopic binary. If a space vehicle is inserted into an orbit about the Earth, the moon, or a planet, it will form an artificial spectroscopic binary, since Doppler-shifted frequency information can be supplied by a continuous-wave transmitter carried in the vehicle. On the basis of the time and frequency variable signal received on Earth, it is possible to determine the orbit of the space vehicle, since the moon or planet's orbit is already known.

Theory of known landmark trackers (KLT's) and unknown landmark trackers (ULT's) is well established. Known landmark trackers were flown on Apollo missions with limited success in Earth orbit, but were effective in lunar orbit. Unknown landmark trackers have been test-flown, but development has been highly classified, and therefore, the results of flight tests are not available. Acquisition theory has not yet been validated. Combination of ULT's and KLT's into one sensor and software package appears desirable to take advantage of the best features of each. Development of adaptive optimal filtering techniques is required. For KLT, the location of several suitable landmarks on the Earth's surface near the expected ground trace of the planned experimental flights must be accurately surveyed.

Normally, the systems of interest in this research cluster are thought of as being completely automatic; for various navigation and guidance concepts, however, it is desirable to determine what a participating crewman can contribute in terms of increased accuracy, decreased time to obtain navigation data, and increased reliability.

3. Description of Research

The research in this research cluster is addressed to the evaluation of selected components, elements, and subsystems of equipment for performing navigation and guidance functions for a manned spaceflight vehicle and to evaluation of the part that man can play in enhancing and optimizing the operation of these subsystems.

The four experiments are concerned with different techniques of obtaining navigation data (use of laser ranging, landmark trackers, and spectroscopic binary satellites), two of which obtain data by tracking ground targets while the third is concerned with navigation satellites.

It is desirable that this research be implemented at an early date, but long lead-time considerations in availability of the appropriate navigational satellites and the necessary ground surveys of Earth landmarks preclude performing most of this research before 1976 at the earliest. After its inception, however, the necessary research can be completed within 12 to 18 months.

Crew participation in the experiments of this cluster will be fairly heavy at the beginning of each experiment, when the greatest concern is with man's abilities in assisting the equipment in acquiring and tracking targets. Subsequent experiment data collection will be limited to monitoring system operation, periodic adjustments of equipment, and data management.

Research cluster 1-EE-4-1 Onboard Laser Ranging will evaluate the capability of an onboard laser-ranging device to provide several precise altitude or range positions per orbit by tracking ground-positioned corner reflectors and ground landmarks, such as mountains, islands, or other prominent landmarks. Evaluations will be made for various slant ranges, altitudes, and atmospheric conditions. The measurement program will determine the ability of the laser device to lock on and track targets. The accuracy with which the device measures altitude or range will be determined by comparing navigation system accuracy with laser ranging vs no laser ranging and vs ground tracking system results. In this experiment, the experimental laser device will be used, for the period of the experiment, as an operational part of the integrated automatic navigation system. Experimental runs will be scheduled to occur weekly, with each run covering three orbits.

Research cluster 1-EE-4-2 Interplanetary or Translunar Navigation by Spectroscopic Binary Satellite will evaluate the capability of onboard navigation systems to determine vehicle positions and velocity (and hence its orbital parameters), using a navigation satellite (artificial spectroscopic binary) located at ranges greater than 40,000 miles from the space vehicle. The experiment consists of a microwave or laser transmitter on the satellite with a receiver aboard the space vehicle to measure Doppler frequency and line of sight. History of the Doppler frequency over one orbit of the spectroscopic binary satellite determines the satellite period and the space vehicle's velocity with respect to the satellite.

Research cluster 1-EE-4-3 Landmark Tracker Orbital Navigation will evaluate the use of KLT's and ULT's for orbital navigation. Accuracy, reliability, and acquisition capabilities will be determined as well as the feasibility and desirability of incorporating KLT's and ULT's into a single sensor and software package. The experiment involves use of landmark tracker data in conjunction with inertial attitude data (from star trackers) to update space vehicle orbital parameters. These data will be compared with data derived from ground tracking to evaluate the experimental system.

Research Cluster 1-EE-4-4 Navigation/Subsystem Candidate Evaluation will evaluate alternate or simultaneous use of integrated candidate systems, such as stellar sensors, Earth attitude sensors, inertial measurement units, position sensors, satellite sensors, sun sensors, planet sensors, ranging devices, and radar altimeters, for accuracy, reliability, maintainability, precision, and response time. A number of different combinations or configurations of the candidate system elements will be used at different periods in the course of the research program. Parameters to be measured include the orbiting vehicle's attitude, position, and velocity vectors. Crewmen will operate pointing and tracking telescopes and space sextants, and provide on-the-spot evaluation, maintenance, and alignment.

4. Impact on Spacecraft

The experiments in this research cluster are strongly correlated with navigation experiments in the 5-NS series and may in certain cases use some of the same hardware. Experimental equipment requiring accommodation includes laser ranging devices, landmark trackers, and perhaps transmitters and receivers if operational hardware cannot be used. The space vehicle must have the capability for switching the experimental devices into the operational navigation system.

Power requirements for the experiments described will average 70 to 100 w. A considerable amount of onboard data storage will be needed for reference data in connection with these experiments. Onboard computation for deriving orbital parameters will be extensive, but this involves only an increase in the computer load, not in capability, which is assumed to exist in the operational system.

All of the experiments in this cluster are sensitive to space vehicle disturbances and generally require correlation of experimental data with space vehicle inertial attitude. It will thus be necessary for the spacecraft to provide inertial attitude information to the experiment and to maintain attitude during critical measurement periods.

5. Required Supporting Technology Development

State-of-the-art advancements are needed in onboard laser ranging systems and landmark tracking systems.

6. References

1. Earth Orbital Experiment Program and Requirements Study, Scientific and Technological Objectives. L13-9852, NASA Langley Research Center, Hampton, Virginia, July 28, 1969.

2. Experiment Program for Extended Earth Missions (Yellow Book), Volume II: Engineering and Technology. NASA September 1, 1969.

3. Space Station Definition, Volume 5: Subsystems. MDC G0605, McDonnell Douglas Astronautics Company, July 1970.

Critical Issues Addressed by Research Cluster

1-EE-4-1

ONBOARD LASER RANGING

1.2.4.1.1.1
What navigation accuracy can be obtained using onboard laser ranging to ground based optical prisms?

1.2.4.1.1.2
What scheme is optimum for acquisition and tracking of the ground prism by the laser beam transmitter?

1.2.4.1.1.3
Do the prism areas derived theoretically provide the desired reflected signal strength?

1.2.4.1.3.3.1
How accurately can Earth orbital navigation be conducted using signal transmission on the spacecraft and reflection by transponders accurately located on Earth?

Critical Issues Addressed by Research Cluster

1-EE-4-2

INTERPLANETARY OR TRANSLUNAR NAVIGATION BY SPECTROSCOPIC BINARY SATELLITE

1.2.4.1.3.2.1

How accurately can ranging to a cooperative synchronous satellite be accomplished for Earth-orbital navigation?

1.2.4.1.3.2.2

What navigation accuracies are possible using navigation satellites as artificial spectroscopic binaries (satellite transmits continuous signal for Doppler frequency measurements, discloses its orbital elements and provides standard time signals) to provide data for interplanetary navigation?

Critical Issues Addressed by Research Cluster

1-EE-4-3

LANDMARK TRACKER ORBITAL NAVIGATION

KNOWN LANDMARK TRACKERS

1.2.4.1.4.3.1
What number of landmarks must be used to ensure four or more navigation updates during one orbit?

1.2.4.1.4.3.2
Does pattern recognition work reliably?

UNKNOWN LANDMARK TRACKERS

1.2.4.1.4.4.1
Can man-in-the-loop significantly increase acquisition capability and reduce amount of computerized search logic required?

1.2.4.1.4.4.2
Are accuracy and reliability in unmanned applications suitable for accurate long term navigation required for orbit keeping and experiment support?

Critical Issues Addressed by Research Cluster

1-EE-4-4

NAVIGATION/SUBSYSTEM CANDIDATE EVALUATION

1.2.4.1.3.3.1
How accurately can Earth orbital navigation be conducted using signal transmission on the spacecraft and reflection by transponders accurately located on earth?

1.2.4.1.4.1.1
What are practical limits between field of view and accuracy requirements for star trackers and what resolution of electronic scan devices is required to provide these limits?

1.2.4.1.4.2.1
Are angular accuracies better than 2 arc-seconds realizable for sun sensors?

1.2.4.1.4.2.2
Can same accuracy be obtained for sun sensors in and out of Earth's atmosphere?

1.2.4.1.4.2.3
Will proposed schemes for heat transfer from optics resolve thermal stability problems for high accuracy sun sensors?

EARTH ORBITAL EXPERIMENT PROGRAM
AND REQUIREMENTS STUDY

MANNED SPACEFLIGHT CAPABILITY

RESEARCH CLUSTER—1-EE-5
COMMUNICATIONS

C-1-295

RESEARCH CLUSTER SYNOPSIS--MANNED SPACEFLIGHT CAPABILITY
1-EE-5
Communications

1. Research Objectives

The objective of the research cluster concerned with communications is to determine the feasibility of high-data-rate, long-range optical communications.

The research associated with this research cluster was suggested by the specific, NASA, long-range objective, "Identify requirements and develop equipment and procedures to assure the effectiveness of man in pursuit of science experiments, applications tasks, and vehicle operations such as telescope operations, laboratory techniques, extravehicular activities, rescue, docking and cargo handling." The subject research cluster pertains to the area of vehicle operations.

Seven critical issues in the area of communications were derived and included under the headings: Repair, Auxiliary Emergency Systems, Space Station to/from Ground, Space Station to/from other Spacecraft, Communication with EVA Astronauts, and Space Station to/from Deep Space Vehicles. The present experiment is related only to the last of these categories and is concerned with optical communications reliability.

2. Background and Current Status

Laser Communication Systems offer new carriers for intelligence. As the radio frequency spectrum becomes more occupied, laser wavelengths will be used to supply additional communication channels.

In communication systems, laser carriers have the advantage of having much higher frequency than microwave carriers. Such high frequencies allow more channels to be placed side by side on a single carrier and the carrier modulated at higher rates. The short wavelength means that smaller antennas with high pointing accuracy can be achieved. Thus, a laser system would have advantages in communications over great distances in space.

The use of lasers in spacecraft-to-spacecraft communications should be more simple than surface-to-spacecraft communication since the laser beam is thereby relieved of the deleterious effects of the atmosphere.

Such a system is within present development capabilities.

3. Description of Research

Communications at optical frequencies offer the best possibility of achieving very high data rates over very long paths. However, to realize this performance the optical beam width must be very narrow. This experiment would evaluate the ability of the system to maintain communications in the presence of operational disturbances, such as spacecraft quiver, high relative velocities of receiver and transmitter, extraneous light from Earth, sun and moon, occultation, etc. The procedure would be to establish a pre-arranged transmission code, so that errors in reception could be correlated with events in the operational situation. In this way, the influence of operational perturbations can be identified and quantitized.

This research cluster is concerned with communication between a manned spacecraft and a deep space vehicle (DSV). The manned spacecraft would include a telescope, pointing controls, receiver, message storage and analysis, power supplies, and a precise timing synchronizer. The DSV would contain a CO_2 laser transmitter, Pockels cell modulator, gimbaled refracting telescope for antenna, power supplies, message storage, precise timing synchronizer, and telescope pointing controls.

On the DSV, the laser generates a constant wavelength signal, which is modulated by the Pockels cell. The signal is focused and aimed by the telescope. On the manned facility, the signal is received by the telescope, demodulated by the detector, amplified by the receiver, and fed into a correlator to compare the received signal with the stored signal which should have been received at that instant. The precise timing circuits on both vehicles are synchronized so that the stored message on the manned vehicle can be compared with the received signal, as a function of time. On radio command to the DSV, the transmitter is turned on with no modulation and the telescope aimed toward the manned spacecraft. The telescope is then aligned precisely by radio command (a slow process requiring an operator) and the parameters of the system are adjusted for optimum signal. The DSV is then commanded to start modulation, and the experiment begins.

During the experiment, the equipment can run automatically, if an "outage" alarm is provided when signal is lost. Then the experiment must be re-initiated, using the procedure given above.

4. Impact on Spacecraft

The items of equipment mentioned in the research cluster description will form a relatively compact package and would not place excessive weight and volume requirements on the spacecraft. The average power is expected to be about 50 watts and remain relatively constant at this level during the course of the experiment. Crew time will be minimal, limited to periodic monitoring by one crewman.

5. Required Supporting Technology Development

An integrated optical communication transmission and receiver system must be developed which includes the components listed in the research cluster description for the spacecraft and deep space vehicle.

The components for both aspects, transmission and receiving, exist, but the accurate pointing and acquisition of a laser beam over large spatial distances has not yet been accomplished.

6. References

1. Scientific and Technical Objectives, Earth Orbital Experiment Program and Requirements Study. L13-9852, NASA Langley Research Center, Hampton, Virginia. July 28, 1969.

Critical Issues Addressed by Research Cluster

1-EE-5

COMMUNICATIONS

1.2.5.4.1.1

Optical Communication Reliability (Vehicle to Deep Space Vehicle). An extended program of transmission from the DSV to the manned vehicle would be undertaken using a prearranged coded message. The error rate and signal-to-noise would be measured under typical operating conditions, which would include effects caused by relative vehicle velocities, pointing errors, delay in acquisition after occlusion, etc.

TABLE 1. LEGEND OF CODES USED IN CREW ACTIVITY MATRIX

Table 1 explains the codes used in the following crew activity matrices. The matrices summarize the inflight crew tasks required to conduct and support the research identified in the research cluster synopses.

TYPE OF ACTIVITY

0 - Not covered below
1 - Experimental subject
2 - Spacecraft operations
3 - Preexperiment and post-experiment equipment preparation
4 - Maintenance of equipment
5 - Conduct of experiment
6 - Evaluate intermediate results
7 - Direct observation of phenomena
8 - Data handling
9 - Communications: initiate and receive transmissions (telemetry, voice)

CREW SKILL

Each code includes a number describing the discipline and a letter describing level of skill:

0 - No special skill required
1 - Medicine
2 - Biology
3 - Physiology
4 - Psychology
5 - Engineering
6 - Astronomy
7 - Physics
8 - Oceanography
9 - Forestry
10 - Agriculture
11 - Geology
12 - Meteorology
13 - Geography
14 - Cartography
15 - Hydrology
16 - Navigation
17 - Communications
18 - Radiology
19 - Instrumentation
20 - Photography
21 - Astronaut
22 - Other

A - Professional level, usually representing Master's degree or higher in discipline.

B - Technician level, requiring several years of training in discipline but requiring no formal degree.

C - Cross-training to the specific task listed, which usually can be taught in three months or less.

START

Year of initial capability to perform task, if after 1974.

DURATION

1 - 1/2 year or less
2 - 1/2 to 1 year
3 - 1 to 2 years
4 - 2 to 3 years
5 - 3 to 4 years
6 - more than 4 years

TASK CONCURRENCY

Indicates other tasks that must be done concurrently with given task.

CREW ACTIVITY MATRIX

RESEARCH CLUSTER		TASK DESCRIPTION	EXPERIMENT EQUIPMENT	TYPE OF ACTIVITY †	PECULIAR ENVIRONMENTAL REQUIREMENTS	EXCLUSIVE ‡	CREW SKILL †	FREQUENCY	TASK TIME (MIN)	NO. OF CREWMEN	START †	DURATION †	TASK [illegible] †
1-EE-3-1	1)	Mount and align gyros and other necessary experimental instrumentation in module while docked to space station.	Attitude [illegible] Alignment [illegible] Star Tracker Tools	3	May require EVA	x	19-B	Once	120	2	1979	-	
	2)	Adjust initial gimbal angles before each run (a run assumed to be the two months module is on station).		4	NONE	x	19-B	1/2 mo.	10	1	1979	2	
	3)	Initiate experiment (warm up and uncage gyros) and initiate transmittal of data from module to space station.	Space Station	5	NONE	x	19-B	1/2 mo.	60	1	1979	2	
	4)	Monitor display of inertial attitude reference signal, gyro environmental temperature, and gyro output signal.	Control/Display Console	5	NONE		5-A	Inter-mittent	30/ day	1	1979	2	
	5)	Adjust gyro temperatures.	"	5	NONE	x	5-C	As Nec-essary	5	1	1979	2	
	6)	Assess attitude and drift measurements for plausibility (compare with estimates of nominal drift).	"	5	NONE	x	5-A	Daily	5	1	1979	2	
	7)	Control and monitor recording of data.	Data Recorders Control/Display Console	8	NONE		Data Mgmt-B	Inter-mittent	5/ day	1	1979	2	
	8)	Terminate Experiment Operation.	Control/Display Console	3	NONE	x	19-B	1/2 mo	15	1	1979	2	

†See Legend of Codes. ‡X (or other entry) indicates that time of crew member(s) cannot be shared with any other task.

C-7

CREW ACTIVITY MATRIX

RESEARCH CLUSTER	TASK DESCRIPTION	EXPERIMENT EQUIPMENT	TYPE OF ACTIVITY †	PECULIAR ENVIRONMENTAL REQUIREMENTS	EXCLUSIVE ‡	CREW SKILL †	FREQUENCY	TASK TIME (MIN)	NO. OF CREWMEN	START †	DURATION †	TASK COMMONALITY †
1-EE-3-2 -1	Prepare and checkout equipment (Mount and align accelerometer package, Connect power supply and recording equipment).		3	Extraneous disturbances must be avoided.	x	5-B	Once	30	1	1974	-	
-2	Initiate measurement period for specified disturbance (Crew Motion, Docking, Rotating Devices, Liquid Circulation).		5	Eliminate or identify other disturbances.	x	5-B	1/mo	5	1	1974	2	
-3	Monitor recording equipment and extraneous disturbances during measurement period.		5, 8			5-B	1/mo	1-10	1	1974	2	Task 4, 5
-4	Assess intermediate results by comparing recording with a priori estimates, and with ground based data.		6			5-B	1/mo	(1-10)	1	1974	2	Task 3, 5
-5	Minimize vehicle disturbance environmental conditions to extent possible during measurements.	Spacecraft controls	2	Thrust operation and vehicle maneuvers must be minimized.	x	21-A	21	1-10	1	1974	2	Task 3, 4

†See Legend of Codes.　　‡X (or other entry) indicates that time of crew member(s) cannot be shared with any other task.

CREW ACTIVITY MATRIX

RESEARCH CLUSTER	TASK DESCRIPTION	EXPERIMENT EQUIPMENT	TYPE OF ACTIVITY †	PECULIAR ENVIRONMENTAL REQUIREMENTS	EXCLUSIVE ‡	CREW SKILL †	FREQUENCY	TASK TIME (MIN)	NO. OF CREWMEN	START †	DURATION †	TASK [illegible] †
1-EB-3-3	1) Check accumulation of biowaste gas in accumulator		3			5-C	1/day	20	1	1972	2	
	2) Activate sensors, recording measurement and control instruments.		3			5-B	Once	30	1	"	"	
Δ	3) Adjust electric thruster RCS power		3			5-A	Once	30	1	"	"	
	4) Activate mass flow meter to thrusters		5			5-B	Once	5	1	"	"	
*	5) Monitor variables		5			5-B	3/day	30	1	"	"	
	6) Adjust operating parameters		5			5-A	3/day	30	1	"	"	
	7) Analyze test data.		6			5-A	1/week	60	1	"	"	
	8) Perform maintenance and repair		4		+	5-C	1/week	60	1	"	"	
	9) Terminate experiment		5			5-B	Once	30	1	"	"	

Δ RCS operation parameter sensing and test will be mainly automatic with optional override.

* Continuous during start-up for one-half hour.

\+ May require EVA for thruster replacement.

†See Legend of Codes. ‡X (or other entry) indicates that time of crew member(s) cannot be shared with any other task.

CREW ACTIVITY MATRIX

RESEARCH CLUSTER	TASK DESCRIPTION	EXPERIMENT EQUIPMENT	TYPE OF ACTIVITY †	PECULIAR ENVIRONMENTAL REQUIREMENTS	EXCLUSIVE †	CREW SKILL†	FREQUENCY	TASK TIME (MIN)	NO. OF CREWMEN	START†	DURATION†	TASK [illegible] †
1-EE-4-1 (1)	Prepare for experiment run (Call up data from storage on landmarks to be used; record atmospheric conditions, current vehicle position, orbital parameters; review procedures for experimental run).	Computer, Keyboard, CRT Scope	3	None	X	16-A	1/week	40	1	1976	2	
(2)	Align and maintain vehicle attitude	Vehicle control: Inertial Attitude Sensors (Sun, star, horizon)	2	None		21-A	1/week	270	1	1976	2	
	(NOTE: VEHICLE ATTITUDE MUST BE MAINTAINED DURING THE ENTIRE PERIOD OF THE EXPERIMENTAL RUN)											
(3)	Begin experiment run by switching laser ranging device into operational navigation system.	Control/Display Console.	5	None	X	16-C	1/week	2	1	1976	2	
(4)	Visually identify first landmark to be tracked	Window	7	None	X	16-A	1/week	(10)*	1	1976	2	
(5)	Slave laser device to and manually point with pointing and tracking telescope to align laser to desired landmark.		5	None	X	16-A	1/week	(5)	1	1976	2	
(6)	Visually observe and record cloud cover, terrain illumination while landmark is being tracked automatically.	Window	7	None		16-A	1/week	(6-20)	1	1976	2	Tasks 7,8.
(7)	Observe and record vehicle oscillations, orbit-keeping functions, atmospheric acceleration perturbation data while landmark is being tracked automatically.	Control/Display Console.	8	None		5-B	1/week	(6-20)	1	1976	2	Tasks 6,8.
(8)	Monitor that target lock-on has occurred and is maintained.	Laser output on C/D Console.	6	None		5-B	1/week	(6-20)				Tasks 6,7.
(9)	Repeat Tasks 4 through 8 for additional landmarks during 3-orbit experimental run.							270	1	1976	2	
(10)	Terminate experiment run by switching laser device off-line.	Control/Display Console	3	None	X	16-C	1/week	2	1	1976	2	
(11)	Evaluate experiment results and proper system operation (compare navigation system accuracy with laser ranging versus no laser ranging and with ground tracking system results, visually observe laser and computer outputs to verify proper system operation).	Historical Data Storage, Control/Display Console, CRT Scope	6&8	None		16-A	1/week	270	1	1976	2	
(12)	Periodically calibrate, adjust, and maintain laser ranging equipment.	Tools & Spares	4	None	X	5-B	Intermittent	30/week	1	1976	2	

*All numbers in parenthesis are included in the 270-minute time for total experiment run.
†See Legend of Codes, X (or other entry) indicates that time of crew member(s) cannot be shared with any other task.

CREW ACTIVITY MATRIX

RESEARCH CLUSTER	TASK DESCRIPTION	EXPERIMENT EQUIPMENT	TYPE OF ACTIVITY †	PECULIAR ENVIRONMENTAL REQUIREMENTS	EXCLUSIVE ‡	CREW SKILL †	FREQUENCY	TASK TIME (MIN.)	NO. OF CREWMEN	START †	DURATION †	TASK CONCURRENCY †
1-EE-4-2	Navigation by Spectroscopic Binary Satellite											
	(1) Activate navigational equipment	spectroscopic binary navigation	3		X	16C	*note below	5	1	Post '80	*note below	
	(2) Initialize spacecraft alignment ...	attitude sensors and laser	3		X	16C or 21A	"	5	1	"	"	
		doppler equipment										
	(3) Orient vehicle to receive satellite signal	inertial measurement unit	3		X	16C or 21A	"	15	1	"	"	
	(4) Enter doppler frequency, line of sight, standard	onboard computer	5		X	16C	"	10	1	"	"	
	time, and satellite orbit into onboard computer											
	(5) Monitor attitude and parameter values on	computer display	5			16C	"	60	1	"	"	
	computer display											
	(6) Compare values with results of ground	onboard computer	8		X	16C	"	10	1	"	"	
	tracking station											
	(7) Correct and adjust alignment as necessary	spacecraft	4		X	16C or 21A	"	5	1	"	"	
		guidance system										

*Once per hour for 12 hours; cycle to be repeated once per week for 12 weeks.
†See Legend of Codes.
‡X (or other entry) indicates that time of crew member(s) cannot be shared with any other task.

CREW ACTIVITY MATRIX

RESEARCH CLUSTER	TASK DESCRIPTION	EXPERIMENT EQUIPMENT	TYPE OF ACTIVITY†	PECULIAR ENVIRONMENTAL REQUIREMENTS	EXCLUSIVE‡	CREW SKILL†	FREQUENCY	TASK TIME (MIN)	NO. OF CREWMEN	START†	DURATION†	TASK [illegible]†
1-EE-4-3	UNKNOWN LANDMARK TRACKER (Tasks 1-9)											
	(1) Activate tracking equipment	landmark tracker	3		X	16-C	3 Times per year	5	1	1978	6 weeks	
	(2) Initiate slewing of telescope to preselected stars.	star tracker, telescope	3		X	16-C	" " " "	3	1	1979	"	
	(3) Initiate slewing of tracking telescope to preselected media.	landmark tracker, telescope	3		X	16-C	" " " "	3	1	"	"	
	(4) Initiate scan mode for tracking equipment	landmark tracker	3		X	16-C	" " " "	2	1	"	"	
	(5) Monitor equipment operation	" "	5			16-C	" " " "	120	1	"	"	Task 8.
	(6) Record landmarks that appear trackable but which trackers would not acquire.	magnetic tape	5		X	16-C	" " " "	15	1	"	"	Tasks 6&9
	(7) Record comments on possible problems	" "	8		X	16-C	" " " "	15	1	"	"	Task 6.
	(8) Monitor orbit parameter updates	Computer displays	5			16-C	" " " "	120	1	"	"	Task 5.
	(9) Record evaluations of tracker performance on acquired targets	magnetic tape	8		X	16-C	" " " "	15	1	"	"	Task 6.
	KNOWN LANDMARKTRACKER (Tasks 10-12)											
	(10) Obtain information from files on cataloged landmarks.	cataloged landmarks.	3		X	16-C	" " " "	20	1	"	"	
	(11) Direct telescope at cataloged landmark	landmarker tracker telescope	5			16-C	" " " "	120	1	"	"	
	(12) Record remarks on performance of tracking system	magnetic tape	8		X	16-C	" " " "	15	1	"	"	

†See Legend of Codes.

‡X (or other entry) indicates that time of crew member(s) cannot be shared with any other task.

CREW ACTIVITY MATRIX

RESEARCH CLUSTER	Task Description	Experiment Equipment	Type of Activity†	Peculiar Environmental Requirements	Exclusive‡	Crew Skill†	Frequency	Task Time (Min)	No. of Crewmen	Start†	Duration†	Task Concurrency†
1-EE-4-4*	NAVIGATION SUBSYSTEM CANDIDATE EVALUATION											
	(1) Activate desired system loop	position attitude sensors	3		X	16-B	Once/ week	5	1	1972	2 yrs	
	(2) Initiate attitude sensors		3		X	16-B	Once/ week	5	1	1972	2 yrs	
	(3) Initiate position sensor		3		X	16-B	Once/ week	5	1	1972	2 yrs	Task 6
	(4) Initiate monitoring equipment	Recorders computer display	5		X	16-B	Once/ week	5	1	1972	2 yrs	
	(5) Record land marks, atmospheric conditions	Magnetic tape	5		X	16-A	Once/ week	90	1	1972	2 yrs	Task 12
	(6) Operate acquisition telescope (manual mode) and/or sextant		5		X	16-A	Once/ week	30	1	1972	2 yrs	Task 3
	(7) Compare results with ground tracking system	Digital display	6		X	16-A	Once/ week	60	1	1972	2 yrs	
	(8) Insert new attitude sensors		5		X	16-B	Once/ week	5	1	1972	2 yrs	
	(9) Insert new position sensors		5		X	16-B	Once/ week	5	1	1972	2 yrs	
	(10) Adjust, repair and maintain		4		X	16-B	Once/ month	60	1	1972	2 yrs	
	(11) Compare accuracy of loops against each other and with standards	Computer displays plus observations	6		X	16-A	Once/ week	60	1	1972	2 yrs	
	(12) Monitor orbit parameter updates	Computer displays	5		X	16-B	Once/ week	30	1	1972	2 yrs	Task 3 and 5
	(13) Terminate experiment		5		X	16-B	Once/ week	5	1	1972	2 yrs	

*Experiment run for a complete orbit.

†See Legend of Codes, ‡X (or other entry) indicates that time of crew member(s) cannot be shared with any other task.

CREW ACTIVITY MATRIX

RESEARCH CLUSTER	TASK DESCRIPTION	EXPERIMENT EQUIPMENT	TYPE OF ACTIVITY†	PECULIAR ENVIRONMENTAL REQUIREMENTS	EXCLUSIVE‡	CREW SKILL†	FREQUENCY	TASK TIME (MIN)	NO. OF CREWMEN	START†	DURATION†	TASK CONCURRENCY†
1-EE-5	Optical Communications in Deep Space											
	1) Assemble and adjust receiving system as necessary	optical communication receiving system.	3		X	3C	Once only	180	1	Post 1980	—	
	2) Initiate radio command to deep space vehicle (DSV) to turn on transmitter.	" " "	3		X	3C	Once per hour	2	1	Post 1980	12 hours	
	3) Align telescope by radio command until signal is acquired.	" " "	3		X	3C	Once per hour	8	1	Post 1980	12 hours	
	4) Adjust system parameters for optimum signal	" " "	3		X	3C	Once per hour	3	1	Post 1980	12 hours	
	5) Initiate signal modulation in DSV by radio command	" " "	5		X	3C	Once per hour	2	1	Post 1980	12 hours	
	6) Monitor link component parameters, e.g., voltage, temperature.	" " "	4			3C	Once per hour	30	1	Post 1980		
	7) Respond to lost-signal alarm	" " "	4		X	3C	Once per hour	1	1	Post 1980	12 hours	
	8) Repeat tasks "(2)" through "(5)".	" " "	—		X	3C	Once per hour	15	1	Post 1980	12 hours	

†See Legend of Codes. ‡X (or other entry) indicates that time of crew member(s) cannot be shared with any other task.

EARTH ORBITAL EXPERIMENT PROGRAM AND REQUIREMENTS STUDY

MANNED SPACEFLIGHT CAPABILITY

RESEARCH CLUSTER—1-OE-1
LOGISTICS AND RESUPPLY (2 PARTS)

C-1-308

RESEARCH CLUSTER SYNOPSIS--MANNED SPACEFLIGHT CAPABILITY
1-OE-1
Logistics and Resupply

1. Research Objectives

The overall objectives of this research cluster are (1) the evaluation of logistics and resupply operational procedures and mechanical aids; and (2) the evaluation and development of tools, aids, and procedures for handling emergency and rescue operations that may be required during long-duration spaceflights.

This research was suggested by two NASA specific, long-range objectives to:

1. Identify requirements and develop equipment and procedures to assure the effectiveness of man in the pursuit of science experiments, applications tasks, and vehicle operations, such as telescope operations, laboratory techniques, extravehicular activities (EVA), rescue, docking, and cargo handling.

2. Develop and gain operating experience related to the resupply and maintenance of multimanned space research facilities. This would include the resupply of expendables as well as equipment and experiment payloads.

Only those aspects of the NASA objectives concerned with logistics, resupply, and emergency and rescue operations are treated in this research cluster.

An analysis of the potential areas of space logistics and resupply warranting research in space resulted in the identification of 13 critical issues, categorized under the headings of Interfaces, Operations, Data Capsules, Personnel, and Rescue/Operations.

In general, data associated with operations experiments will be derived from actual spacecraft operations and will result from the application of various techniques, mechanical aids, and system concepts to cargo handling and related tasks, and from the evaluation of the effectiveness of each. Emergency and rescue operations will, of course, be simulated in the experimental situation.

2. Background and Current Status

The docking and extravehicular activities associated with the Gemini flights were not designed for the purpose of evaluating logistic techniques and, consequently, did not contribute definitive information to this area; the activities did, however, give some insight into the difficulties that may be encountered in such tasks and thereby permitted a more realistic evaluation of potential concepts and techniques.

The equipment transfer between the Apollo Command Module and the Lunar Excursion Module was more directly applicable to the types of tasks considered in this research cluster and did contribute information of value.

Actual experience with large cargo deliveries, a major concern in this research cluster, will not be acquired from present space flight programs.

Experience with spacecraft emergencies in the Mercury, Gemini, and Apollo flights can provide valuable input to assist in meeting the objectives of this research cluster. Though these emergencies were unplanned, the reactions of the crew and their suggestions for handling similar emergencies should be considered baseline in examining additional emergency procedures in space. Unfortunately, detailed information on these previous manned spaceflight programs is not readily available to the scientific community. It would appear desirable to institute an effort to consolidate these data centrally and make them available on a much wider basis than has hitherto been the case.

3. Description of Research

Methods of transferring, handling, and storing packaged cargo, fluids, and large pieces of equipment will be evaluated during actual space operations. This includes such activities as transfer of the goods from the earth orbital shuttle (EOS) to the space research facility, and handling it inside and outside the facility during usage. Rails, cables, umbilicals, and mechanical aids will be compared for effectiveness. Data will be collected on transfer time, ease of handling, required skill level, expended astronaut effort, and cargo damage or loss. Supply container disposal and other waste-product disposal methods will also be evaluated.

The logistics and resupply experiments rely on time and motion studies, as well as subjective evaluation by the astronauts for both procedures and equipment. There is a high probability that all assigned tasks will be successfully completed. Thus, the evaluation is primarily concerned with convenience, effort, and time.

Initial concepts for transferring cargo of various types will be evaluated. It is assumed that the EOS logistic module will be docked to the space research facility and that it will be capable of being pressurized. It is also assumed that the module will remain docked until another module arrives, at which time it will be returned to Earth. During the time it is docked, equipment and consumables will be transferred to the research facility and waste products will be returned to the module.

If operationally installed, a track or rail system extending from the logistic module interior to appropriate points within the research facility will be evaluated to determine its utility in handling cargo. Location of astronaut mobility aids, such as handholds, rails, footholds (including Velcro strips), and body restraints, established as a result of ground research, will be assessed during orbital operations. Skill in maneuvering high-mass containers by hand, rail, and gas-jet thrusters will be determined for as many astronauts as possible. Various fixtures for performing logistic tasks will be compared.

Bulk liquids, such as propellants for the research facility control rockets, will be transferred from the logistic module supply tanks by umbilical lines. Methods for controlling propellant spillage upon disconnect will be evaluated. Results of these evaluations may lead to revisions in unloading procedures, container design, and mechanical aid design.

EVA cargo transfer will be carefully evaluated to determine whether improvements should be made in equipment or procecures. These cargos include antennas, antenna booms, and other equipment to be mounted externally on the space research facility. Final planning for evaluations of these EVA logistics will be made when specific operations and logistic aids have been selected (i.e., space tugs, transfer booms, or cranes). Criteria to be used include time for transfer and required astronaut skill level.

Evaluations of both intravehicular activity (IVA) and EVA logistics will make extensive use of time and motion studies by trained observers. Motion pictures will be taken for subsequent study. Thus, most logistic activities that require substantial effort or are time-critical will involve an observer and photographer in addition to the logistics personnel. Such studies will be continued until satisfactory procedures and equipment are evolved.

Emergency and rescue operations consist of several experiments to be conducted both inside and outside of the spacecraft. The safety of the astronauts and the spacecraft is the primary consideration in resolving any emergency. The major factor in assessing all safety and rescue experiments is the time required to alleviate immediate dangers. This depends upon astronaut reaction time, mobility, effectiveness of emergency aids, and procedural efficiency. Experiments will be conducted by simulating actual emergencies as closely as possible.

A major consideration in extravehicular activities is astronaut safety and retrieval in case of emergency. Several of the emergencies could result in death unless immediate steps are taken by the endangered astronaut, by a companion either inside or outside the spacecraft, or by automatic devices.

The major hazards that would cause an emergency are envisioned as:

1. Malfunction or damage to space suit or life support pack.

2. Astronaut injury or sickness.

3. Solar-flare radiation hazard.

4. Astronaut fatigue.

In the case of complete oxygen starvation, the astronaut may survive for about two minutes. Even with momentary loss of pressure, unconsciousness will occur in about 8 seconds, and the astronaut is unable to help himself. Other emergencies may allow a longer reaction time for corrective action.

The objective of the EVA experiments is to determine by simulation what corrective action is feasible. This means (1) establishing effectiveness of emergency monitoring devices and (2) establishing the best method and time to bring the astronaut to a safe condition. For most emergencies, a safe condition will be achieved by returning to an airlock. Techniques and devices to be evaluated include the following:

1. Astronaut retrieval via tether line. Until more is learned about EVA, the use of tether lines must be continued. Simulated emergencies will evaluate effectiveness of the tether in returning the astronaut to an airlock. A single astronaut will exit from the spacecraft through an airlock. The outer hatch of the airlock will be left open, and a tether cord will be fastened between the spacecraft and the astronaut. From different locations on the spacecraft exterior and at various distances and directions from the craft, the time required to return to the airlock will be determined. Entering and securing the outer hatch, and repressurizing the airlock will be included in the overall time. The first experiments will assume self-retrieval; that is, the astronaut is conscious and able to pull himself back via the tether. A second set of experiments will assume that the astronaut is unconscious or disabled and unable to assist in his own rescue. An anthropomorphic dummy should be used to simulate the disabled astronaut in this case. A take-up reel for the tether cord is envisioned, as well as automatic hatch closure and airlock repressurization.

   These trials will help determine the maximum terminal velocities that can be tolerated as the astronaut approaches the hatch area. Such devices as inflated impact rings or nets around the hatch will be evaluated. Also to be evaluated will be tether booms that will minimize whipping and wrap-around problems caused by miss-match between the astronaut and spacecraft orbits, and the resulting problem of momentum conservation as final hatch closure is attempted.

2. Astronaut retrieval via jet thruster. If tether cords prove awkward and seriously impede EVA, mobility and emergency retrieval may be possible with hand-held or strap-on thrusters. Again, time for return to the air-lock is the important factor in determining effectiveness. Because closure path corrections are readily made by pointing the thruster in the desired direction, jet thrusters avoid the relative velocity and closure vector problems of tether retrieval. As retrieval of an unconscious astronaut requires remote control of a thrust pack attached to the astronaut, an anthropomorphic dummy should be used. If such sophisticated equipment is used, appropriate EVA evaluations will be included.

3. Astronaut retrieval by another astronaut. When an astronaut is unable to return to the spacecraft by himself or cannot be returned by remote control, a second astronaut must bring him back (assuming he is within EVA range). This experiment will begin with one astronaut performing normal operational EV activities and a second astronaut inside the spacecraft partially suited-up. Time for rescue will be determined from notification of emergency condition to when the rescued astronaut is returned to an airlock. Tethers and jet thrusters will both be used by the assisting astronaut.

   Techniques for providing on-the-spot emergency oxygen will be evaluated during ground simulations. These include a plug-in hose from the assisting astronaut's supply, a spare pack carried from the spacecraft, and a supply hose reeled out from the airlock. The latter is also used as a retrieval tether.

4. Guide cables or rails. Because there are few EVA requirements where the astronaut must work at a remote distance from the spacecraft, guide cables or rails may be used. These devices will be mounted before launch or attached to the spacecraft as one of the first extravehicular activities. Although their prime purpose is to facilitate mobility from place to place over the spacecraft surface, they will greatly reduce the time required in making an emergency return to an airlock. Astronaut retrieval will be evaluated for self-powered return, remote return via tether line (while the astronaut

is attached to guide cable), and return via jet thruster. This experiment is closely coordinated with the evaluation of mobility aids.

5. Emergency monitoring devices. Routine checks of voice communication systems, space suit temperatures, oxygen consumption rates, and reserve supply indicators will be made during all EVA experiments. The basic worth of these devices will already have been established by ground tests.

Intravehicular activities require establishment and evaluation of emergency and rescue procedures. The emergencies considered herein are of a general nature and are restricted to activities within the spacecraft. The major emphasis is on protecting the astronaut from both immediate danger and possible future dangers. Evaluation of emergency procedures will include:

1. Evacuation from one compartment to another. Simulated emergencies (such as loss of cabin pressure or fire, etc.) will be staged in one of the spacecraft compartments, and the time to evacuate to an adjoining compartment will be determined. The evacuees will start from various areas of the endangered compartment and will be engaged in various activities when the emergency signal is given.

2. Isolation of one or more compartments. Because several spacecraft designs provide a number of compartments that can be sealed from one another, practice drills will be conducted where various compartments or areas of the spacecraft are sealed off. The emergency drills will include identification of the endangered area, hatch or bulkhead sealing order, and crew accountability.

3. Evaluation of emergency monitoring devices. IVA emergency monitoring devices, such as voice communication, temperature sensors for fire, cabin pressure, and atmospheric fouling, will be routinely checked during IVA experiments. The basic worth of these devices will already have been established by ground tests.

4. Impact on Spacecraft

The experiments related to space logistics and resupply will have a very minor impact on the space research facility; the tasks will be actual cargo handling and transfer operations, performed as a normal mission activity. The equipment used to evaluate the experimental techniques and mechanical aids will consist primarily of a motion picture camera and timer; and the resulting data, in most instances, will be simple digital scores or film that will be returned to Earth for thorough analysis. Two crew members must be available for task evaluation, one for observation and one for photography; consequently, they cannot participate in logistic activities. The spacecraft crew must be large enough to allow for this situation.

The experiments related to emergency and rescue operations are also expected to have a minor impact. Most of the evaluations will be based on observation, and oxygen consumption and heart rate will be measured. The simulation of rescue operations may involve some EVA activity in excess of normal operations. Oxygen and other life support supplies for these activities must be estimated and added to the vehicle's supplies.

5. Required Supporting Technology Development
No development of concepts or equipment will be required to carry out the objectives of this research cluster. A large amount of experimental equipment will be tested in evaluating logistics and rescue operations, but these items are not considered developmental items for operations experiments.

6. References

1. Second National Conference on Space Maintenance and Extravehicular Activities. Summary of Presentations. Las Vegas, Nevada, August 6-8, 1968.

2. Earth Orbital Experiment Program and Requirements Study, Scientific and Technical Objectives. L12-9852, NASA Langley Research Center, Hampton, Virginia, July 28, 1969.

3. Experiment Program for Extended Earth Orbital Missions (Yellow Book), Volume II; Engineering and Technology. National Aeronautics and Space Administration, September 1, 1969.

Critical Issues Addressed by Research Cluster

1-OE-1-1

SPACE LOGISTICS AND RESUPPLY

1.3.1.1.1.1
What are the design requirements for docking ports for cluster and large modules as well as small man-transfer units considering positioning guidance, restraint (latching or other), safety?

1.3.1.1.2.1
What are the design requirements for hatches and airlocks in order to satisfy speed, gas dump, size compatibility with various elements to be transferred, seal protection, safety?

1.3.1.1.4.1
What are the design requirements for proximity restraints and position controls such as tie downs, clamps, cables, booms, Velcro?

1.3.1.1.5.1
What are the design requirements for umbilicals in order to accomplish safe liquid, gas, or power transfers; disconnects, remote operations of high pressure systems, purging and dump?

1.3.1.1.6.1
What are the design requirements for transfer tunnels for solids, man, supplies and their use in proximity or long distance operations?

1.3.1.1.6.2
What are the design requirements for transfer cables and guides for proximity and long distance movement of elements?

1.3.1.2.5.1
Cargo transfer and storage operations in space or IVA; what are the various container shapes, location and storage procedures best suited for space station efficiency and flexibility?

1.3.1.2.6.1
What techniques are best applicable to a safe disposal of used items? Different orbits? Deorbiting? Controlled Captivity?

CRITICAL ISSUES ADDRESSED BY RESEARCH CLUSTER 1-OE-1-2
Emergency and Rescue Operations

1.3.1.5.1.1
What is the effectiveness of space emergency monitoring aids using contact between the space research facility and the operation through (a) visual means, (b) verbal contact, and (c) automated position and status sensors?

1.3.1.5.2.1
What are the emergency shelters, their location and frequency in order to allow for partial or total emergencies? Consider (a) airlocks, (b) tunnels and holds, (c) emergency supplies and (d) life support systems.

1.3.1.5.4.1
What is man's capability to effect rescue? Consider (a) mobility and time to reach critical area using various mobility aids, (b) acquisition and restraints on man or manned/unmanned modules, (c) use of emergency tools to reach man and (d) first aid if required.

1.3.1.5.4.2
What is man's capability to conduct rescue operations during space research facility emergencies? What are the tools and aids required to conduct these operations by man or by remote control, including ground control?

1.3.1.5.5.1
What remote control units are required for rescue and emergency situations such as fire or other hazard not allowing proximity approach? Consider (a) monitoring aids required to maintain contact under emergency conditions and over long distances, (b) various IVA and EVA mobility aids, and (c) emergency return units (individual or multi-personnel).

RESEARCH CLUSTER SYNOPSIS--MANNED SPACEFLIGHT CAPABILITY
1-OE-2
Maintenance, Repair, and Retrofit

1. Research Objectives

This research cluster is concerned with in-space evaluation of the equipment, procedures, and manned skills required to perform (1) maintenance and repair functions, both IVA and EVA, and (2) retrofit or reconfiguration functions in which an entire spacecraft may, over an extended period of time, be completely refurbished and equipped to perform experimental tasks more effectively, in a more sophisticated way, with more accuracy and precision, or even to perform completely different experiments than were originally programmed. The emphasis then is not only on those activities traditionally thought of as being in-flight maintenance, but also on the unique type of activities that have been usually reserved for major overhaul facilities.

NASA long-range objectives and anticipated future positions of value were analyzed in detail to delineate the research for this experiment group. The following specific objectives contained in Reference 1 were given particular attention as being most relevant to the projected future position of having a large permanent general research, development, and operational facility in space:

1. Develop long-duration systems which utilize high reliability components to minimize resupply and repair requirements, and which also take advantage of modular techniques to allow use of on-orbit maintenance and repair in case of failure.

2. Define and develop a modular space research facility concept which offers flexibility to adapt to changing mission requirements and payloads.

3. Develop operator equipment and technology for maintenance internal and external to the space vehicle.

4. Develop and demonstrate, under operational conditions, suitable EVA and IVA modes of operation for routine and emergency activities.

5. Develop and gain operating experience related to the resupply and maintenance of multimanned space research facilities. This would include the resupply of expendables as well as equipment and experiment payloads.

Under the three headings of maintenance, repair, and retrofit, critical issues were identified by pursuing two analytical paths -- one addressed to hardware questions (e.g., under remove and replace maintenance detailed examination was made of components, sensors, filters, insulation, protective covers, and electro-mechanical elements), and the other addressed to the functional effectiveness of man in performing maintenance (e.g., sensory, energy expenditures, accessibility and mobility).

2. Background and Current Status

For large general purpose laboratories designed to remain in Earth orbit for as long as ten years, in-flight maintenance, repair, and retrofit is mandatory to provide continuous operation for those hardware elements which cannot achieve such long-term reliability, to permit incorporation of new state-of-the-art hardware as it becomes available over the years, and to give flexibility in programming different experiments as research needs change. The capability for completely reconfiguring a ten-year space research facility is an especially unique concept which requires considerable study, ground based development and research, and early evaluation in space.

A vast amount of ground based data have been accumulated on performance of maintenance activities by man and on the related design discipline of maintainability. Considerable effort has also been addressed to in-flight maintenance, especially as associated with aircraft maintenance. Some extremely sophisticated techniques have been developed for in-flight trouble shooting and identification of needed repairs which, however, are usually made on the ground after flight. Very little information is available on the many problems inherent in maintaining, in-flight, the complex, long-life systems anticipated for advanced spacecraft.

Experience in the Mercury, Gemini, and Apollo programs has shown that space maintenance is feasible since the crews responded adequately to the failures which occurred. In general it was concluded that, given the proper tools and aids and proper design of prime equipment, an astronaut can perform just about as well in space as on the ground. This generalization may not hold true for EVA maintenance, since difficulty was encountered in even some of the relatively simple EVA activities, and times and energy expenditures exceeded greatly those experienced in ground-based simulations.

Maintenance and retrofit activities will be planned and carried out in early space missions such as SKYLAB A and anticipated follow-on flights. It is imperative that a program of carefully controlled observations and measurements be planned to take advantage of those opportunities and obtain data which can be used in developing appropriate hardware, procedures, and training for the crews who will be manning longer duration spacecraft.

3. Description of Research

The research contemplated in this research cluster should be performed at the earliest opportunity and continue for several years, with two years being sufficient to obtain most of the necessary data. In general this research effort is confined to observation and measurement of maintenance, repair, and retrofit operations conducted as a normal part of operating the in-orbit space vehicle. For some types of maintenance, however, simulation is necessary to verify and gain experience in an operation so that when the failure does actually occur it can be attended to safely and effectively. These activities include those which might be hazardous, are unpredictable in occurrence, may not occur until years of flight have been accumulated, or about which large gaps of knowledge exist.

The 28 critical issues generated in response to the objectives of this research cluster will be answered by controlled observations of onboard crewmen while they are performing routine maintenance, repair, and retrofit operations. Opportunities for such measurement will occur randomly in practically any of the experiments described in this entire study. The observational and measurement methodology required to obtain these data is described in Research Cluster 1-BR-3, "Complex Task Behavior," and includes use of TV cameras, timers, biomedical instrumentation, and crew voice logs to measure task times and errors, energy expenditure, difficulties encountered, and crew subjective evaluations. For these reasons, a detailed research cluster description was not prepared for this area.

4. Impact on Space Research Facilities

The major impact of this research cluster is in the area of EVA activity required of the crew. Many of the EVA trips can be combined, however, to perform functions for more than one experiment, thus making a realistic estimate something like one EVA per week.

Power requirements for the measurement devices to be used in this research cluster are provided for use also in a number of other experiments so they do not impose any additional weight or volume penalties. Operation of TV cameras and video recorders in support of this research cluster will total about 4 hours per month, while tape recorder usage will be about 2 hours per month. The major impact on the communications system will be that imposed by the broad band video data which, however, may be stored on tape and returned to ground via logistics vehicle.

5. Required Supporting Technology Development

No major research and technology advancements are required for conduct of this research cluster.

6. References

1. Earth Orbital Experiment Program and Requirements Study, Scientific and Technological Objectives, NASA Langley Research Center, Hampton, Virginia, L12-9852, July 28, 1969.

2. Peter N. Van Schaik, Man's Changing Role in EVA Space, Second National Conference on Space Maintenance and Extravehicular Activities, Las Vegas, Nevada, August 6-8, 1968.

3. Otto F. Trout, Jr. and Paul R. Hill, Human Work Performance in Space, in Second National Conference on Space Maintenance and Extravehicular Activities, Las Vegas, Nevada, August 6-8, 1968.

Critical Issues Addressed by Research Cluster

1-OE-2

MAINTENANCE, REPAIR, AND RETROFIT

1.2.2.1.1.5
Rigid and semirigid Solar Cell Arrays - Cell/Module/Panel replacement in orbit.

1.2.2.1.3.6
Roll-up Solar Cell Arrays - Cell/Module replacement in orbit.

1.2.2.2.2.3
What is the effect of space on individual cell and battery maintenance and replacement (electrically hot)?

1.2.4.1.2.2
Can the sensing elements (gyros and accelerometors) of Strapdown Inertial Measurement Units be replaced and accurately calibrated onboard?

1.2.5.1.1.1
Repair of expandable antenna by EVA astronaut. This critical issue relates closely to those involved in the manual capabilities of the EVA astronaut.

1.3.2.1.1.2
What is man's capability in various lighting, contrasts and field of view constraints to visually sense discoloration, contamination, or wear in various surfaces such as mirrors, thermal paints, covers, cables?

1.3.2.1.1.3
What is man's capability in various lighting, contrasts and field of view constraints to visually sense cracks and scratches?

1.3.2.1.1.4
What is man's capability in various lighting, contrasts and field of view constraints to visually sense leaks or condensation of liquids and gases?

1.3.2.1.1.5
What is man's capability in various lighting, contrasts and field of view constraints to visually sense loose hardware, debris and dust?

1.3.2.1.2.1
What is man's capability to use smells of various fluids including hot areas (or fire) emissions to provide leakage, operational or malfunctions sensing?

1.3.2.1.3.1
What is man's capability in shirtsleeve, IVA, and EVA conditions to use his touch to sense surface finishes and deterioration or defects?

1.3.2.1.3.2
What is man's capability in shirtsleeve, IVA, and EVA conditions to use his touch to sense temperatures?

1.3.2.1.3.3
What is man's capability in shirtsleeve, IVA, and EVA conditions to use his touch to sense moisture, condensates or deposits on various surfaces?

1.3.2.1.3.4
What is man's capability in shirtsleeve, IVA, and EVA conditions to use his touch to sense pressure leaks?

1.3.2.1.4.1
What is man's capability under shirtsleeve, IVA, and EVA conditions to use his hearing ability to sense fluid leaks?

1.3.2.1.4.2
What is man's capability under shirtsleeve, IVA, and EVA conditions to use his hearing ability to sense malfunctioning or wear signs in mechanisms?

1.3.2.1.4.3
What is man's capability under shirtsleeve, IVA, and EVA conditions to use his hearing ability to sense impact or meteoroids or other loose objects?

1.3.2.1.4.4
What is man's capability under shirtsleeve, IVA, and EVA conditions to use his hearing ability to sense valves or moving components operation?

1.3.2.2.1.1
What is man's capability, using free hands and various handwear (IVA, EVA), to handle small items (washers, screws, seals, etc.) or to reach into small areas (such as removing "O" ring seals, pins, etc.).

1.3.2.2.2.1
What are man's space constrained accessibility limits while in shirtsleeve, IVA, or EVA conditions for hand reach and motion capability?

1.3.2.2.2.2
What are man's space constrained accessibility limits while in shirtsleeve, IVA, or EVA conditions for minimum space requirements for torso or two hands?

1.3.2.2.2.3
What are man's space constrained accessibility limits while in shirtsleeve, IVA, or EVA conditions for full body minimum space allocation?

1.3.2.2.2.4
What are man's space constrained accessibility limits while in shirtsleeve, IVA, or EVA conditions for access to hard-to-reach areas?

1.3.2.2.3.1
What is man's capability, on a noninterference basis, to work in proximity with others while using various IVA and EVA suits or backpacks (motion, air, etc.).

1.3.2.3.2
What is man's capability in shirtsleeve, IVA, and EVA conditions to accomplish a coordinated task using various tools and operations? For example, time and energy allocation to move to a solar panel (EVA), inspect panel, disconnect, remove and replace with a new panel, reconnect, check out, dispose of damaged panel and return to base.

1.3.2.4.1
What is man's capability in shirtsleeve, IVA, and EVA conditions to make use of the following tools? Consider size and shape, counterforce application, body restraints and supports, space and access limitations, debris, residuals collection, retention of loose items, and safety requirements.

(a) Hand operated tools — Torqueing, squeezing, sawing, hammering, etc.

(b) Hand held power tools

(c) Welders — fluid lines, automatic welding, structural, manual or automatic control, torch cutting

(d) Brazing — fluid lines

(e) Soldering — electronic/electromechanical

(f) Bonding — structural or nonstructural assembly and positioning

(g) Foam-in-place dispensers — repair of pressure shells

(h) Augmented reach tools – proximity tools using mechanical extensions and controls

1.3.2.4.2

What are the required aids in order to allow man to perform the required operations?

(a) Body restraints and positioning aids

(b) Components transfer aids – rails, cables, powered motion aids, bumpers, restraints

(c) Alignment aids – optical instruments, distance measurements, preloads in structure, and springs.

(d) Sensors – leak detection, surface contamination, properties, abrasion, oxidation, cracks, etc.; heat, debris and dust, moisture/condensates, gases, cracks, insulation systems degradation

1.3.2.4.3

How is man's capability improved by artificial gravity, specifically when doing complex operations on small elements and components?

RESEARCH CLUSTER SYNOPSIS--MANNED SPACEFLIGHT CAPABILITY
1-OE-3
Assembly and Deployment

1. Research Objectives

The Assembly and Deployment research cluster has as its ultimate objective the determination of man's ability to perform EVA assembly and erection of large space structures. This objective includes crew work performance in terms of time and efficiency for the assembly and deployment of an antenna boom and dish. These objectives will be realized by the actual assembly and deployment of a prefabricated antenna designed specifically for EVA space utilization.

The work crew's physiological condition will be monitored and recorded during the assembly phase. This experiment will permit additional evaluation of Locomotion and Restraint Aids (1-MM-2) and Performance Aids (tools) (1-MM-5). After erection of the antenna it will be monitored to determine its ability to withstand the warping effects due to space temperatures and inadvertent vehicle accelerations.

Depending on the crew's ability to erect the antenna and the antenna's ability to survive in space, determinations will be made for future planning for lightweight man-erectable or heavier automated structures.

The research included in this research cluster is addressed to 11 critical issues categorized under the headings of Operations Experiments, Assembly and Deployment which were derived from a detailed analysis of a NASA long-range objective in the Man-Systems Integration Program which asks the question, "How can operational capability to assemble and deploy lightweight and large expandable space structures and man's capability to support assembly and deployment be evaluated in space?"

2. Background and Current Status

The background for this research cluster is necessarily limited as only very minor EVA tasks have been accomplished in a space environment. The Apollo 11 and 12 lunar EVA proved that man can survive for extended periods in a space vacuum and accomplish specific tasks when he is provided the proper physical restraints. With this confidence and knowledge the next progressive step is to assemble and erect structures in a total space environment. Much will be determined in the use and deployment of restraints and tools on the Skylab A project.

Training and practice on Earth will be most essential if this experiment is to be successful. The Apollo Program proved the validity of underwater (null gravity) simulation for training of various tasks that had been previously identified as high-probability trouble areas.

Tools, restraints and locomotion aids have been developed for various EVA and IVA tasks; however, new and unique equipment must be designed and developed.

A considerable knowledge base exists, having been accumulated on Gemini and Apollo flights, in Air Force laboratories (e. g., Wright Patterson AFB and School of Aviation Medicine), at NASA centers (Langley Research Center, Manned Spacecraft Center, and Marshall Space Flight Center), and at numerous industrial facilities. These resources must be utilized as a broad comprehensive base for the development of the necessary equipment if the objectives of this research cluster are to be implemented.

3. Description of Research

The specific research included in this research cluster can be accomplished in two distinct phases. The first is the assembly and deployment phase which should be accomplished at the earliest time possible in the mission. The antenna can be erected in 16 EVA manhours. After deployment the only EVA required would be for adjustment and maintenance. In the second phase, the antenna observation period, deflection and deformation of the unit will be measured by utilization of a laser. The observation period should be as long as possible, which in turn justifies the early assembly and deployment scheduling.

It is anticipated that the antenna will be approximately 300 feet in diameter, of the unfurlable type, and requiring a support boom approximately 160 feet long. This structure can be designed as a one, two, or three piece beam utilizing lightweight materials in its construction. In addition to unfurlable antennas, advantage will be taken of opportunities to evaluate operations in the deployment of expandable structures such as crew tunnels, EVA maintenance enclosures, and expandable airlocks.

It will be transported into orbit strapped to the side of the launch vehicle or stored in an earth orbital shuttle (EOS) cargo hold. Coupling devices will be provided at the end of each section for manned assembly.

The test program will evaluate the deployment and performance characteristics of the support boom and the physiological capabilities of man to assemble large structures in space. The use of various hand tools and attachment hardware will be evaluated. Photographic and TV coverage and subjective judgment will be the medium for measuring man's performance.

The measurement program will record the time required for deployment, man's endurance level for handling and assembling space erected structures by monitoring heart beat and oxygen consumption, deflections of the boom caused by temperature gradients due to sunlight or shadowing, and the dynamic stability characteristics as a result of crew or space research facility operations.

4. Impact on Spacecraft

The impact upon the spacecraft is primarily in the area of power consumption. During the assembly and deployment phase (8 hours estimated) movie and TV coverage will be continuous. Thereafter during the monitoring phase TV and movie coverage will be minimal. Data recording will be continuous during the construction phase and minimal during the monitoring phase. The two TV cameras will be equipped with pan-tilt heads and zoom lens. Total volume is 0.75 ft^3. They each require 4 watts of power while operating and the total operating time for a 90-day cycle is estimated at 32 hours.

The video tape recorder will be borrowed from other experiments, but will consume approximately 60 watts and operate for 32 hours. The physiological instrumentation is minimal and is included in the Biomedical subdiscipline.

5. Required Supporting Technology Development

Carefully conducted and controlled ground experiments are required to refine assembly techniques and monitoring requirements. Development of tools, locomotion and restraint equipment will be concurrent with the ground experiments.

Define a baseline for comparison to the space activity of the assembly and deployment crew.

6. References

1. Otto F. Trout, Jr., and Paul R. Hill, "Human Work Performance in Space," paper presented at Second National Conference on Space Maintenance and Extravehicular Activities, Las Vegas, Nevada, August 6-8, 1968.

2. "Experiment Requirements Document for Foot Controlled Maneuvering Unit" (Experiment T020), proposed experiment for Skylab, ERD-T020 NASA, January 20, 1970.

3. D. G. Norman and E. S. Miller, "EVA Force Emission Capability in Simulated Zero Gravity," paper presented at Second National Conference on Space Maintenance and Extravehicular Activities, Las Vegas, Nevada, August 6-8, 1968.

4. P. N. Van Schaik, "Man's Changing Role in EVA Space," paper presented at Second National Conference on Space Maintenance and Extravehicular Activities, Las Vegas, Nevada, August 6-8, 1968.

5. D. E. Havens, G. A. Johnson, H. S. Jencks; "Null Gravity Restraint Characteristics," McDonnell Douglas Paper WD 1240, April 1970.

6. "Summary of Gemini Extravehicular Activity," NASA SP-149, 1967.

7. A. E. Wiedell and W. H. Tobey, "A Six-Degree-of-Freedom Simulation Technique for Evaluating Space Mobility Aids and Tasks," paper presented at Second National Conference on Space Maintenance and Extravehicular Activities, Las Vegas, Nevada, August 6-8, 1968.

8. C. B. Nelson, "Simulation of Package Transfer Concepts for Saturn I Orbital Workshop," paper presented at Second National Conference on Space Maintenance and Extravehicular Activities, Las Vegas, Nevada, August 6-8, 1968.

9. "Experiment Integration Requirements Document for Astronaut Maneuvering Equipment" (Experiment M 509), proposed experiment for Skylab, NASA, June 30, 1969.

10. Scientific and Technical Objectives, Earth Orbital Experiment Program and Requirements Study L13-9852, NASA Langley Research Center, Hampton, Virginia, July 28, 1969.

11. Third Aerospace Expandable and Modular Structures Conference, May 16-18, 1967, Air Force Aeropropulsion Laboratory, TR 68-17.

Critical Issues Addressed by Research Cluster

1-OE-3

ASSEMBLY AND DEPLOYMENT

1.3.3.1.1.1.1
What is man's capability to move from one element to another in order to attain control of the unit to be assembled, using various mobility aids?

1.3.3.1.1.1.2
What is the relative effectiveness of manned proximity controls (mechanical arms) and remote control operations during each phase of the assembly process?

1.3.3.1.1.2.1
What is man's capability to attach various guides, restraints and safety devices on the module or elements in an accurate and untangled fashion?

1.3.3.1.1.2.2
What are the effectiveness and operation control advantages of mechanically restrained (rigid, straps, cables, pins, guides) vs. fly-in techniques for:

(a) Proximity positioning
(b) Initial alignment

Linear
Rotational
Angular

(c) Final adjustment

1.3.3.1.1.2.3
What tools and devices are best suited for proximity and fine alignment of modules to be joined?

Rigid elements
Flexible elements
Pins and guides

1.3.3.1.2.1.1
What are the mechanical locking/assembly techniques best suited for man-aided assembly operations in space, especially in nonpermanent assembly requirements? Consider:

Size/weight
Ease and reliability

Strength
Manual vs. augmented or remote control operation

1.3.3.1.2.2.1
What are the structural assembly techniques best suited for man aided assembly operations in space, especially in permanent or semi-permanent assembly requirements? Consider:

Various fastener types
Bonding
Welding

1.3.3.2.1.1
What are the most effective designs for erectable structures (elements assembly) in order to build-up various booms, trusses, shapes (antennas, panels, etc.) in space? Consider:

Fastening
Restraints/handling ease
Alignment

1.3.3.2.2.2
What simplifications and advantages for mechanically deployed structures can be added by manned operations? Consider:

Folded bulk
Deployment aids and power sources
Safety (preloaded devices)
Designs using translation, rotation
Articulations (scissors, accordions, etc.)

1.3.3.2.3.1
What are the most effective designs for expandable structures using various internally pressurized elements applicable to the design of auxiliary structures such as crew transfer tunnels, air locks, maintenance hangars, experiment bays, or living quarters? Consider:

(a) Packaging requirements/techniques
(b) Packaged bulk
(c) Deployment aids—pressure/techniques
(d) Rigidization requirements/techniques
(e) Man rated requirements
(f) Retraction requirements/techniques

1.3.3.2.4.1

In addition to the specific design features, what are the relative merits of the three deployment methods outlined above? Consider:

(a) Deployed size limitation due to manned constraints, specifically for erection type elements

(b) Stability in space, considering thermal deflections and operational loads

(c) Safety, considering rigidity of the structure, damage susceptibility failure mode

(d) Reusability and adaptation to various requirements during the life span of the space research facility (commonality)

(e) Aids for manned inspection transfers

(f) Flexibility for modification

(g) Ease of disposal or disassembly

(h) Ability to support umbilicals and other interfaces

(i) Alignment capability and accuracy; ease of alignment

(j) What is their adaptability to direct or remote control operations during buildup, alignment and activation?

RESEARCH CLUSTER SYNOPSIS--MANNED SPACEFLIGHT CAPABILITY
1-OE-4
Module Operations

1. Research Objectives

The research included in this research cluster is addressed to evaluation of operational procedures, equipment, and man/machine interfaces involved in the on-orbit operation of experiment modules flown in conjunction with a manned orbital spacecraft. The experimental data to be collected are restricted to free flying modules, but it is confidently expected that the results will have direct applicability to modules which are attached to the space research facility.

The research content of this research cluster was derived by detailed analysis of the following NASA long-range objectives for manned spaceflight:

1. To develop and operate spacecraft modules that could accommodate up to 12 men and can support laboratories and observatories for the pursuit of science, applications, and technology goals, and incorporate the capability to support space operations such as providing services to satellites or remotely operated modules.

2. Establish and use first generation laboratories and observatories to be operated in conjunction with the space research facility for the conduct of programs in one or more of the following fields: astronomical observatories; biomedical and biosciences investigations; processing of unique materials and production of unique elements of systems; and the conduct of observations and operations related to man's knowledge of his environment on Earth.

Critical issues were identified through a process of breaking the above objectives down into lower tier subobjectives. They included critical issues involving data management, control and guidance, power, and communications and covered such diverse areas as hangar concepts, viewing requirements, spacecraft support requirements, retrieving module data, module station-keeping, and rendezvous and docking.

Repeated observations for a number of years for various types of modules are required to adequately assess the operational systems for effective, long-term operation of experiment modules from a spacecraft.

2. Background and Current Status

The NASA long-range scientific and technological objectives envision a number of small space research facilities (or modules) capable of carrying out a wide range of scientific and applied missions.

Considerable experience has been gained during the past few years in operating unmanned satellites from ground stations. Control and servicing of such vehicles from an orbital manned vehicle appears to offer many advantages.

Various studies (References 3, 4, 5) have advocated the use of free-flying modules or attached modules operating in conjunction with manned space research facilities.

Special module studies have been conducted to identify the types of experimentation most appropriate for free-flying and attached modules, to define the characteristics of such modules, and to determine optimum modes of operation. All systems of this type have common problems including rendezvous and docking, communication between module and manned vehicle, deployment and retrieval, and maintenance. Basic data on these problem areas have been derived from the space program to date, but many details remain to be resolved by in-space evaluation. Ground-based simulations will establish procedures for rendezvous, docking, and special handling requirements and will be verified during orbital operations.

3. Description of Research

The research contemplated by this research cluster is directed toward evaluating procedures, equipment, and human capabilities in the support of free-flying modules by a manned space research facility. It is concerned with the operations of (1) module station-keeping, (2) monitoring and communicating with modules, (3) controlling module experimental and support equipment, (4) deployment and retrieval, and (5) module maintenance and reconfiguration. It is not concerned with the specifics of the particular experiment (e.g., Astronomy, Space Physics) which the module is performing.

Data collection will begin with initial operation of the first free-flying module, assumed to be launched in early 1979, and data will be collected during the initial 3 to 6 months of module operation. Data will be collected on the same basis for subsequent free flying modules, which it is assumed will be launched on a 1 per year basis through 1986.

During the data collection periods the following operations will take place: (1) rendezvous and docking, (2) manned operations in maintaining, resupplying, and reconfiguring modules while docked to the spacecraft, (3) Deployment and retrieval of modules, and (4) remote monitoring and control of module operations, subsystem status, and attitude. The module will initially rendezvous with, and dock to, the spacecraft for checkout and maintenance. It will subsequently return to the spacecraft and dock approximately every 2 months. Remote monitoring and control from the spacecraft will be highly automated but will require crew attention for short periods each day.

Measurement parameters include crew task times, crew errors, metabolic rates, quality of displayed data, and response of module systems. Much of the data can be obtained directly from the operational instrumentation and recorded without manned intervention in the measurement and data handling process. For some operations, direct observational data will be obtained by means of TV cameras. In general, data will be collated by the data management system and telemetered to the ground for analysis.

Crew involvement is heavy during periods of module deployment, retrieval, rendezvous and docking, and while the module is docked to the spacecraft, but will be minimal during module station keeping.

4. Impact on Spacecraft
Though the impact of free-flying modules on the space research facility is great, the data collection requirements for this research cluster do not impose severe additional requirements. The major equipment impact is on the module monitor and control console, which must be equipped with timers and must be instrumented to provide readouts to the data management system of data for this cluster. The data management system must provide computer programs to control acquisition and collation of data readouts, storage for the data, and capability for periodically telemetering these data to ground stations.

TV camera and video recording capability will be provided as a requirement of other experiments. Use time for this equipment will be a maximum of 4 hours every 2 months.

Audio recording capability will also be provided as a requirement of other experiments. Use of the tape recorders for this research cluster will be approximately 30 min every 2 months.

5. Required Supporting Technology Development
No STD requirements have been identified for this research cluster.

6. References

1. Earth Orbital Experiment Program and Requirements Study, Scientific and Technological Objectives, NASA Langley Research Center, Hampton, Virginia, L13-9852, July 28, 1969.

2. Proceedings of the Winter Study on Uses of Manned Space Flight, 1975 to 1985. A Conference held in La Jolla, California, December 6-9, 1968. Vols, I and II, NASA, Washington, D.C., 1969.

3. Space Research--Directions for the Future. Report of a Study by the Space Sciences Board. Part Three. Woods Hole, Massachusetts, 1965, Space Sciences Board, NAS/NRC, Washington D.C., February 1966.

4. Experiment Modules. Volume VII of Space Station Definition. McDonnell Douglas Astronautics Co., MDC G0605, July 1970.

5. Experiment Program for Extended Earth Orbital Missions (Yellow Book), National Aeronautics and Space Administration, September 1, 1969.

Critical Issues Addressed by Research Cluster
1-OE-4
MODULE OPERATIONS

1.3.1.2.1.1
What are the problems of acquisition of various units in the space research facility proximity or in a compatible orbit (satellite)?

1.3.1.2.1.2
What is man's capability to steer close to unit and effect a "hookup" in a safe and non-damaging manner?

1.3.1.2.1.3
What are the tools and aids that best support these operations?

1.3.1.2.3.1
(a) Restraint and positioning of units of satellite and (b) docking to compatible units. What are the best procedures and designs?

1.3.4.2.1.1
To what accuracy can the inertial orientation of the unmanned module be controlled during brief and extended periods of time?

1.3.4.2.1.2
To what extent can the module be rate-stabilized during brief and extended periods of time?

1.3.4.2.3.1
What disturbances of the module are caused by man in an EVA mode?

1.3.4.2.4.1
What disturbances are exerted on the module due to launch and docking?

1.3.4.2.5.1
What minimum drift rates of the detached module, relative to the space vehicle, can be achieved?

1.3.4.2.5.2
What is the optimum separation distance between module and space vehicle?

1.3.4.2.6.1
How precisely can the separation distance between module and vehicle be determined?

1.3.5.3.2.1
What pointing accuracy can be maintained by an instrument on the vehicle while viewing a target fixed in inertial space?

1.3.5.3.3.1
With what accuracy can an instrument on the vehicle track (a) a target on Earth, (b) the module?

1.3.5.3.4.1
How efficiently can man guide and control himself while traveling between the vehicle and the remote module for close monitoring?

1.3.5.3.4.2
How far can man safely venture from the space vehicle for monitoring and other functions?

RESEARCH CLUSTER SYNOPSIS—MANNED SPACEFLIGHT CAPABILITY
1-OE-5
Vehicle Support Operations

1. Research Objectives

This research cluster is concerned with the following six types of vehicle support operations: Medical Services, Food Management, Data Management, Power Management, Vehicle Control, and Communications. Its objectives are (1) the accumulation of data to assist mission planners in determining which support operations for given missions should be performed by central vehicle support services and which should be performed by the individual crewmen requiring the support service; and (2) the on-orbit evaluation of equipment, procedures, and skills for providing such support services.

The critical issues that dictated the content of this research cluster were identified through an in-depth analysis of the following NASA long-range objectives, which are to:

1. Identify requirements and develop equipment and procedures to assure the effectiveness of man in the pursuit of science experiments, application tasks, and vehicle operations.

2. Identify requirements and develop techniques to conduct activities in support of major scientific and applied disciplines.

3. Develop and operate space research facility modules that could accommodate up to 12 men and support laboratories and observatories for the pursuit of science, applications, and technology goals.

4. Define and develop predictive, diagnostic, and therapeutic procedures, medications, and equipment to maintain the health and well-being of a spacecraft crew.

5. Quantify human capabilities for performing physical and mental work and provide data for decisions on the appropriate man-machine mix.

6. Develop technically and esthetically acceptable techniques and hardware for providing personal accommodations in the area of food management.

An extended period of on-orbit observations of these support operations is required to accumulate the necessary base of data and to provide design information for the planners of future systems and missions.

2. Background and Current Status
In the small-vehicle, short-mission, minimum-crew-size space missions flown to date, there has been very little specialization, with crew members being cross-trained in all of the mission's functions. Each crewman performed the tasks necessary to supply his own medical, food-management, and data-management needs, and for the most part he was capable of performing any of the necessary power-management, vehicle-control, and communications tasks. There is little doubt that for missions of this type, such an arrangement is not only highly feasible but also relatively economical in terms of training time and crew on-orbit operational time.

With larger vehicles, larger crews, and longer and more diverse missions, however, it will be come more economical and more efficient to provide these support services as a central function performed by specialized personnel. Few guidelines presently exist to assist planners in making decisions regarding allocation of support services, and these decisions must be made early in a developmental program because the choices will directly influence crew selection, crew training, and the design of the facilities themselves. What is needed is identification of the crossover points for each of the various types of support operations and for the various parameters that influence these decisions, such as crew size, mission duration, type of mission, and size of vehicle.

Design criteria for facilities, equipment, and procedures for centrally supplied support services in a space vehicle are also not available. In this area, designers can draw heavily upon ground-based technology, and initial systems will undoubtedly reflect this influence. Because of the apparent differences between terrestrial and space conditions, however, it will be necessary to evaluate facilities, equipment, and procedures in space and to derive new or updated design criteria where necessary.

3. Description of Research
The operations of interest in this research cluster are not in themselves experimental, but are operations that must be performed on any manned space research facility dedicated to the conduct of experiments. They are similar in that they need to be performed for most or all members of a space vehicle and for most (perhaps all) of the experiments on an orbiting laboratory. They are also similar in that they lend themselves to performance by a specialized group of personnel (e. g., medical, food-management, and data-management specialists) and can be performed at a central location within the spacecraft.

The research in this research cluster is divided into the following subgroups:

1. Medical Services.

2. Food Management.

3. Data Management.

4. Power Management.

5. Vehicle Control.

6. Communications.

For each subgroup, observations and measurements will be made for an initial period of 6 months, starting at the first opportunity after space crews of 10 or more persons are available in orbit. When major changes are made in the assignment of responsibilities, in equipment, or in procedure, another 6-month period of observations will begin. These iterations will probably continue for a period of 3 years.

Data on the following parameters will be obtained by use of crew logs, responses to questionnaires, time line of crew time expenditures, and from TV film records of selected operations:

1. Crew time of individual crew members and total time required to provide the support service.

2. Frequency with which the support service is required.

3. Time delays in providing the support service.

4. Availability of equipment when the support service is required.

5. Adequacy of equipment and procedures in providing the support service.

Crew participation in this experiment group will consist of responding to questionnaires, setting up TV cameras and lights, monitoring TV camera and recorder operation, making crew log entries, and monitoring the accumulation and segregation of data for each of the experiment subgroups.

4. Impact on Spacecraft

Measurement and recording equipment for this research cluster includes TV cameras, supplemental lighting, and video recorders, tape recorders, and an input keyboard and computer—all of which are required and provided by Research Cluster 1-BR-2. The equipment required to provide the support services is operational equipment; consequently, the hardware impact on spacecraft is negligible.

Power requirements are those imposed by TV camera and recorder operation for about 1-1/2 hr per month, tape recorder use for about 10 min per week for each crewman, and operation of the data management and display equipment for 90 min per week.

Total crew time demands are estimated (assuming a 10-man crew) at 27 hr per month of exclusive time (time during which the crewman cannot be doing anything else) and 5 hr per month during which the crew member can be performing another nonexclusive task such as monitoring.

5. Required Supporting Technology Development
No support technology development is required.

6. References

1. Earth Orbital Experiment Program and Requirements Study, Scientific and Technological Objectives, L13-9852. NASA, Langley Research Center, Hampton, Virginia, July 28, 1969.

2. Report on the Optimization of the Manned Orbital Research Laboratory (MORL) System Concept, Volume IV. Systems Analysis—Flight Crew, Report SM 46075. Douglas Aircraft Company, Santa Monica, California, September 1964.

3. George E. Mueller. An integrated space program for the next generation. Astronautics and Aeronautics, January 1970, pp. 30-51.

4. Space Station Crew Operations Definitions. Report MDC G0645, McDonnell-Douglas Astronautics Company, August 1970.

Critical Issues Addressed by Research Cluster

1-OE-5

VEHICLE SUPPORT OPERATIONS

1.2.1.1.3.9
What space research facility operational skills will be required to run the computers, or is it advisable for each investigator to be trained to run the computers for his own work?

1.2.1.1.3.11
What digital, analog, hybrid, or special purpose computer requirements of Space Medicine Operations Experiments; and normal housekeeping can be consolidated as (hopefully) one centralized master computing facility?

1.2.1.2.2.6
What are the optical reader requirements of Space Medicine, Operation Experiments, and normal housekeeping, and can these requirements be consolidated?

1.2.1.2.3.4
What personal calculators will be required to support Space Medicine, Operations Experiments, and normal housekeeping; and which of these requirements can be consolidated?

1.2.1.2.4.7
What are the multiplex requirements of Space Medicine, Operations Experiments, and normal housekeeping; and which of these requirements can be consolidated on a noninterference basis?

1.2.1.2.5.6
What are the time base requirements of Space Medicine, Operations Experiments, and normal housekeeping; and how can all these requirements be consolidated with a central time generation system?

1.2.1.2.6.4
How may automatic discriminators serve the requirements of Space Medicine, Operations Experiments, and normal housekeeping; and can these requirements be consolidated?

1.2.1.3.1.2
What specialized peripheral scientific skills will be required of the space research facility computer programmer, or will programming be a secondary skill of some onboard experimenter?

1.2.1.4.2.3
What photographic developing and printing facilities will be required, and how shall these be modified for zero-g operation?

1.2.1.4.2.4
What methods will be required to store both unused and processed photographics, and what retrieval aids will best assist the users?

1.2.1.4.2.5
What hazards to the environmental control system will come from photographic material outgassing?

1.2.1..4.3.4
What advantages could be derived by numerous investigator plug-in points for recording on a central space research facility tape recorder; for example, higher fidelity, parallel recording of real time during critical experiments?

1.2.1.4.3.6
What methods or facilities will best make the transcribed audio tapes more accessible to the investigators and to the pertinent parts of the experiments in question?

1.3.5.3.1.1
To what accuracy can the inertial orientation of the manned vehicle be controlled during brief and extended periods of time?

1.3.4.3.1.2
To what extent can the vehicle be rate-stabilized during brief and extended periods of time?

TABLE 1. LEGEND OF CODES USED IN CREW ACTIVITY MATRIX

Table 1 explains the codes used in the following crew activity matrices. The matrices summarize the inflight crew tasks required to conduct and support the research identified in the research cluster synopses.

TYPE OF ACTIVITY

0 - Not covered below
1 - Experimental subject
2 - Spacecraft operations
3 - Preexperiment and post-experiment equipment preparation
4 - Maintenance of equipment
5 - Conduct of experiment
6 - Evaluate intermediate results
7 - Direct observation of phenomena
8 - Data handling
9 - Communications: initiate and receive transmissions (telemetry, voice)

CREW SKILL

Each code includes a number describing the discipline and a letter describing level of skill:

0 - No special skill required
1 - Medicine
2 - Biology
3 - Physiology
4 - Psychology
5 - Engineering
6 - Astronomy
7 - Physics
8 - Oceanography
9 - Forestry
10 - Agriculture
11 - Geology
12 - Meteorology
13 - Geography
14 - Cartography
15 - Hydrology
16 - Navigation
17 - Communications
18 - Radiology
19 - Instrumentation
20 - Photography
21 - Astronaut
22 - Other

A - Professional level, usually representing Master's degree or higher in discipline.

B - Technician level, requiring several years of training in discipline but requiring no formal degree.

C - Cross-training to the specific task listed, which usually can be taught in three months or less.

START

Year of initial capability to perform task, if after 1974.

DURATION

1 - 1/2 year or less
2 - 1/2 to 1 year
3 - 1 to 2 years
4 - 2 to 3 years
5 - 3 to 4 years
6 - more than 4 years

TASK CONCURRENCY

Indicates other tasks that must be done concurrently with given task.

CREW ACTIVITY MATRIX (Page 1 of 2)

RESEARCH CLUSTER	TASK DESCRIPTION	EXPERIMENT EQUIPMENT	TYPE OF ACTIVITY†	PECULIAR ENVIRONMENTAL REQUIREMENTS	EXCLU-SIVE ‡	CREW SKILL†	FREQUENCY	TASK TIME (MIN)	NO. OF CREWMEN	START†	DURA-TION†	TASK CONCURRENCY†
1-OE-1-1 a.	IVA Cargo Transfer from EOS to Space Station											
(Page 1 of 2)	(1) Assemble work/transfer aids.	work/transfer aids	non-experimental		-	-	-	0	-	'80	-	
	(NOTE: The above task is not an experimental											
	task but is one of the objects of the investigation)											
	(2) Load camera.	camera	3		x	20C	*Note below	5	1	"	MISSION	
	(3) Check out communications and voice recording	communication equipment	3		x	4C	"	10	1	"	"	
	equipment.											
	(4) Observe transfer operations and time activities.	—	5			4B	"	120	1	"	"	Tasks 5 & 6
	(5) Record voice comments.	—	8			4B	"	120	1	"	"	Tasks 4 & 6
	(6) Photograph transfer activities.	camera	5		x	20C	"	120	1	"	"	Tasks 4 & 5
	(7) Unload camera and store film.	—	3 & 8		x	20C	"	10	1	"	"	
	(8) Enter times in permanent data storage.	data sheets or magnetic tape	8		x	4C	"	10	1	"		
	(9) Interview crew concerning opinions of methods	—	5		x	4B	"	30	1	"	"	
	and aids.											
	(10) Serve as subject for interview.	—	1		x	21C	"	30	4			
b.	EVA Cargo Transfer											
	(1) Load camera.	camera	3		x	20C	*Note below	5	1	'80	MISSION	
	(2) Check out communications and voice recording	communication equipment	3		x	4C	"	10	1	"	"	
	equipment.											
	(3) Don space suits.	space suits	3		x	4B & 20C	"	15	2	"	"	
	(4) Exit from spacecraft.	air lock	2			4B & 20C	"	15	2	"	"	
	(5) Observe EVA cargo transfer and time activities.	timer	5			4B	"	240	1	"	"	Tasks 6 & 7
	(6) Record voice comments.	—	8			5B	"	240	1	"	"	Tasks 5 & 7
	(7) Photograph transfer activities.	camera	5		x	20C	"	240	1	"	"	Tasks 5 & 6
*The frequency is governed by the amount of actual cargo transfer required by the mission - with which the experiment will be correlated.												

†See Legend of Codes,

‡X (or other entry) indicates that time of crew member(s) cannot be shared with any other task.

CREW ACTIVITY MATRIX (Page 2 of 2)

RESEARCH CLUSTER	TASK DESCRIPTION	EXPERIMENT EQUIPMENT	TYPE OF ACTIVITY †	PECULIAR ENVIRONMENTAL REQUIREMENTS	EXCLUSIVE ‡	CREW SKILL †	FREQUENCY	TASK TIME (MIN)	NO. OF CREWMEN	START †	DURATION †	TASK CONCURRENCY †
1-OE-1-1 b.	(8) Reenter spacecraft.	air lock	2		x	4B & 20C	*Note Below	15	2	'80	MISSION	
continued	(9) Doff space suits.	space suits	3		x	4B & 20C	"	15	2	"	"	
(Page 2 of 2)	(10) Unload camera and store film.	camera	3 & 8		x	20C	"	10	1	"	"	
	(11) Enter times in permanent data storage.	magnetic tape	8					10	1	"	"	
	(12) Interview crew on their opinions of methods	—	5		x	4B	"	30	1	"	"	
	and aids.											
	(13) Serve as subject for interview.	—	1		x	21C	"	30	4	"	"	

†See Legend of Codes, ‡X (or other entry) indicates that time of crew member(s) cannot be shared with any other task.

RESEARCH CLUSTER
NO. 1-OE-1-2

CREW ACTIVITY MATRIX (page 1 of 2)

RESEARCH CLUSTER	TASK DESCRIPTION	EXPERIMENT EQUIPMENT	TYPE OF ACTIVITY†	PECULIAR ENVIRONMENTAL REQUIREMENTS	EXCLUSIVE‡	CREW SKILL†	FREQUENCY	TASK TIME (MIN)	NO. OF CREWMEN	START†	DURATION†	TASK† CONCURRENCY
1-OE-1-2	EVA Astronaut Retrieval											
(Page 1 of 2)	(1) Discuss simulation.	—	3			4B & 21C		30	4	'80		
	(2) Serve as subject.											
	(a) Don space suit	space suit	1-3		x	21C	**Note Below	15	1	"	**Note Below	
	(b) Exit from spacecraft	air lock	1-2		x	21C	"	15	1	"	"	
	(c) Perform retrieval activities.	—	1-5		x	21C	"	30	1	"	"	
	(d) Reenter spacecraft	air lock	1-2		x	21C	"	15	1	"	"	
	(e) Doff space suit	space suit	1-3		x	21C	"	15	1	"	"	
	(f) Participate in interview	—	1-5		x	21C	"	30	1	"	"	
	(3) Act as rescue astronaut. For fellow astronaut or anthropomorphic dummy											
	(a) Don space suit	space suit	1-3		x	21C	"	15	1	"	"	
	(b) Don accessory equipment (aids)	rescue aids	1-3		x	21C	"	10	1	"	"	
	(c) Exit from spacecraft	space suit	1-2		x	21C	"	15	1	"	"	Task (2)(b)
	(d) Perform rescue operation	—	1-5		x	21C	"	30	1	"	"	Task (2)(c)
	(e) Reenter spacecraft	air lock	1-2		x	21C	"	15	1	"	"	
	(f) Doff space suit	space suit	1-3		x	21C	"	15	1	"	"	
	(g) Participate in interview	—	1-5		x	21C	"	30	1	"	"	
	(4) Act as observer.											
	(a) Load camera	camera	3		x	20C	**Note Below	5	1	'80	**Note below	
	(b) Check out communications and voice recording equipment	communication equipment	3		x	4C	"	10	1	"	"	
	(c) Don space suits	space suit	3		x	4B & 20C	"	15	2	"	"	
	(d) Exit from spacecraft	air lock	2		x	4B & 20C	"	15	2	"	"	
	(e) Observe EVA rescue operations and time activities	—	5			4B	"	30	1	"	"	Tasks f & g
	(f) Record voice comments	—	8			4B	"	30	1	"	"	Tasks e & g
	(g) Photograph rescue operations	camera	5		x	20C	"	30	1	"	"	[illegible]

**Two times per week for the first six weeks, then once every two weeks for the mission duration.

†See Legend of Codes,

‡X (or other entry) indicates that time of crew member(s) cannot be shared with any other task.

CREW ACTIVITY MATRIX (page 2 of 2)

RESEARCH CLUSTER
NO. 1-OE-1-2

RESEARCH CLUSTER	TASK DESCRIPTION	EXPERIMENT EQUIPMENT	TYPE OF ACTIVITY†	PECULIAR ENVIRONMENTAL REQUIREMENTS	EXCLUSIVE ‡	CREW SKILL†	FREQUENCY	TASK TIME (MIN)	NO. OF CREWMEN	START†	DURATION†	TASK† CONCURRENCY
1-OE-1-2	(h) Reenter spacecraft	air lock	2		x	4B& 20C	"	15	2	"	"	
(Page 2 of 2)	(i) Doff space suits	space suit	3		x	4B& 20C	"	15	2	"	"	
	(j) Unload camera and store film	camera	3 & 8		x	20C	"	10	1	"	"	
	(k) Enter times in permanent data storage	data sheets or magnetic tape	8		x	4B	"	10	1	"	"	
	(l) Interview subjects	—	5		x	4B	"	30	1	"	"	
	Evacuation from one compartment to another											
	(1) Rehearse evacuation.	—	3		x	21C	"	30	4	"	"	
	(2) Signal start of simulation.	—	5		x	4B	"	5	1	"	"	
	(3) Observe evacuation and time activities.	timer	5			4B	"	30	1	"	"	Task 4
	(4) Record voice comments.	communication equipment	8			4B	"	30	1	"	"	Task 3
	(5) Enter times in data storage.	data storage	8		x	4B	"	10	1	"	"	
	(6) Interview crew.	—	5		x	4B	"	30	1	"	"	
	(7) Serve as experimental subject.	—	1		x	21C	"	90	4	"	"	
	Compartment Isolation											
	(1) Rehearse drills.	—	3		x	21C	**Note Below	30	4	'80	**Note Below	
	(2) Observe emergency drill performance and time activities.	timer	5		x	4B	"	30	1	"	"	Task 3
	(3) Record times and voice comments.	data storage	8 & 9		x	4B	"	10	1	"	"	Task 2
	(4) Interview crew.	—	5		x	4B	"	30	1	"	"	
	(5) Serve as experimental subjects.							90	4	"	"	

**Two times per week for the first six weeks, then once every two weeks for the mission duration.

†See Legend of Codes, ‡X (or other entry) indicates that time of crew member(s) cannot be shared with any other task.

CREW ACTIVITY MATRIX

RESEARCH CLUSTER	TASK DESCRIPTION	EXPERIMENT EQUIPMENT	TYPE OF ACTIVITY†	PECULIAR ENVIRONMENTAL REQUIREMENTS	EXCLUSIVE‡	CREW SKILL†	FREQUENCY	TASK TIME (MIN)	NO. OF CREWMEN	START†	DURATION†	TASK CONCURRENCY†
1-OE-3 (1)	Unstore and prepare antenna for erection.	Antenna and Accessory Eqpt.	3		x	19-C	Once	60	1	1974	1	
(2)	Checkout tools, attachment hardware and monitoring equipment.	Tool Kit, Laser, Cameras & T.V.	3		x	19-C	Once	10	1	"	1	
(3)	Retrieve and review experiment plan.	--	3		x	19-C	Once	20	1	"	1	
(4)	Brief EVA crew and monitoring crew.	Instruction Material	5		x	21-A	Once	30	1	"	1	
(5)	Unstow and don pressure suits	--	3		x	21-A	10/ 90 days	15	2	"	1	
(6)	Turn on instrumentation.	Test & Monitoring Console.	5		x	19-A	Once	1	1	"	1	
(7)	Perform assembly and deployment of antenna	Experiment Plan	5	EVA Activity	x	21-A	Once	480	2	"	1	
(8)	Observe conduct of experiment.	Viewport T.V. Monitor	5		x	19-A	Once	10	1	"	1	
(9)	Evaluate observation.	--	6		x	19-A	Once	10	1	"	1	
(10)	Record observations.	T.V. Tape Movie Film	8		x	19-C	Once	10	1	"	1	
(11)	Retrieve EVA crews, doff & stow PSA's.	--	5			19-A	Once	20	4	"	1	
(12)	Troubleshoot and repair recording/measuring equipment.	Test Eqpt. and Prints - Plans	4	Possible EVA Activity	x	19-B	9/90 days	20	1	"	1	
(13)	Initiate data recording and data storage.	Test Recording Console	8		x	19-C	Once	Concurrent with Experiment	1	"	1	
(14)	Evaluate data acquisition.	--	6		x	19-A	Once	10	1	"	1	
(15)	Correct for bad data.	--	8		x	19-A	--	10	1	"	1	
(16)	Initiate transmission to ground.	--	9		x	17-B	Once	1	1	"	1	
(17)	Record subjective comments.	Tape Recording	9		x	19-B	Once	30	4	1974	1	
(18)	Adjust, align antenna.	Experiment Plan	4	EVA Activity	x	19-C	9/90 days	30	2	"	1	

†See Legend of Codes.

‡X (or other entry) indicates that time of crew member(s) cannot be shared with any other task.

CREW ACTIVITY MATRIX (Page 1 of 2)

RESEARCH CLUSTER	TASK DESCRIPTION	EXPERIMENT EQUIPMENT	TYPE OF ACTIVITY†	PECULIAR ENVIRONMENTAL REQUIREMENTS	EXCLUSIVE‡	CREW SKILL†	FREQUENCY	TASK TIME (MIN)	NO. OF CREWMEN	START†	DURATION†	TASK CONCURRENCY†
1-OE-4 (page 1 of 2)	1) Initiate and maintain communications with ground during module launch and ascent	Communications Subsystems	9	None	X	17-C	Yearly	60**	1	79	6	
	2) Initiate and maintain communications with logistics vehicle during orbit insertion and rendezvous	Communications	9	None	X	17-C	Yearly	20**	1	79	6	
	3) Perform final rendezvous and docking	Central command console, portable display and control console at docking port, viewport	2	None	X	21-A	1/2 mo.	45**	2	79	6	
	This manual task performed in lieu of the normal automatic rendezvous and docking requires one man at the central command and console and one man at the docking port. Same task for initial operation as for periodic module retrieval.											
	3A) (Normal alternative to Task 3) Monitor final rendezvous and docking	Central command console, portable display and control console at docking port, viewport	2	None	X	21-A	1/2 mo.	45**	2	79	6	
	Crewmen must be prepared to take over if automatic operations malfunction											
	4) Initiate automatic data recording and timer	Controls at central command console	8	None		0-C	1/day	2	1	79	6	
	5) Secure module and prepare for docked operations (checkout, maintenance, resupply)	Connections for pressurization, electrical & other services, central command console	3	May require EVA	X	5-B	1/2 mo.	120**	2	79	6	
	Completion of this task ensures that module is securely docked, the connection is sealed, and the module is environmentally adequate for shirtsleeve occupancy.											
	6) Prepare measurement system (especially TV cameras) for observation	Central command console, TV cameras, video recorder, auxiliary lighting, heart rate, monitoring equipment	3	None	X	19-C	1/2 mo.	20	2	79	6	

**Operational Time — Not chargeable to experiments

†See Legend of Codes.

‡X (or other entry) indicates that time of crew member(s) cannot be shared with any other task.

CREW ACTIVITY MATRIX (Page 2 of 2)

RESEARCH CLUSTER	TASK DESCRIPTION	EXPERIMENT EQUIPMENT	TYPE OF ACTIVITY†	PECULIAR ENVIRONMENTAL REQUIREMENTS	EXCLUSIVE‡	CREW SKILL†	FREQUENCY	TASK TIME (MIN)	NO. OF CREWMEN	START†	DURATION†	TASK CONCURRENCY†
1-OE-4 (page 2 of 2)	7) Perform docked module operations (checkout, maintenance, cleaning, retrieval of data, resupply of film, replenishment of propellant, reconfiguration)	Maintenance tools, central command console	4	May require EVA	X	5-B	1/2 mo.	240**	2	79	6	Task 8*
					*Crewman at central command console can perform Tasks 7 and 8 simultaneously.							
	8) Initiate and monitor collection of experimental data by TV cameras monitor, heart rate monitor, timers	Central command console	5	None		19-C	1/2 mo.	240	1	79	6	Task 7
	9) Prepare module for undocking	Central command console, connections for service	3	May require EVA	X	5-B	1/2 mo.	120**	2	79	6	
	10) Undock and deploy module to stationkeeping position	Central command console, portable C/D console at docking port, viewport	3	None	X	21-A	1/2 mo.	90**	2	79	6	Task 11
	11) Initiate and monitor collection of data during undocking and deployment	Central command console, TV cameras, timers	5	None		19-C	1/2 mo.	90	1	79	6	Task 10
	12) Monitor and control module stationkeeping operations	Central command console	5	None		7-B	Daily	30** (intermittent)	1	79	6	See note
	NOTE: This task can be conducted while crewman performing other station management and traffic control tasks.											
	13) Initiate and monitor collection of data during monitor and control operations	Timers, computer programs	5	None		19-C	Daily	30 (intermittent)	1	79	6	Task 12
	14) Log comments on evaluation of module operations	Tape recorder	8	None	X	0-C	Daily	5-10	1	79	6	
	**Operational Time – Not chargeable to experiments											

†See Legend of Codes, ‡X (or other entry) indicates that time of crew member(s) cannot be shared with any other task.

RESEARCH CLUSTER NO. 1-OE-5

CREW ACTIVITY MATRIX

RESEARCH CLUSTER	TASK DESCRIPTION	EXPERIMENT EQUIPMENT	TYPE OF ACTIVITY†	PECULIAR ENVIRONMENTAL REQUIREMENTS	EXCLUSIVE ‡	CREW SKILL†	FREQUENCY	TASK TIME (MIN)	NO. OF CREWMEN	START†	DURATION†	TASK CONCURRENCY†
1-OE-5	1) Set up and adjust TV cameras and lights	light meter	3	None	X	19C	3/mos	10	1	'75	4 yr	
	2) Monitor operation of TV cameras and recorders	TV monitoring console	5	None		19C	"	30	1	"	"	
	3) Participate as crew member in providing or receiving support services		2	None		22C	10/wk	Varies	all	"	"	
	[This is operational time and not charged to this experiment group]											
	4) Respond to questionnaires	input keyboard, CRT display, computer storage	8	None	X	0-C	1/wk	30	all	"	"	
	5) Make crew log entries	microphone tape recorder	8	None	X	0-C	2/wk	5	all	"	"	
	6) Control and monitor accumulation of data for each experiment subgroup	data management system, recorders keyboard input, CRT display	8	None		22B*	inter-mittent	60 min. per wk	1	"	"	

*Data Management Skills
†See Legend of Codes,

‡X (or other entry) indicates that time of crew member(s) cannot be shared with any other task.